Search for magneto-flicker noise in K†

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(Received 17 June 1974)

A search has been made for a magnetic field-dependent flicker noise in potassium, predicted by the charge-density-wave (CDW) model of the alkali metals. The search was made in high-purity encapsulated K wires over 1 m long with diameters 0.023 and 0.010 in. The specimens were prepared by degassing high-purity K, vacuum filling long thin plastic (0.023-in. i.d.) or cupro-nickel (0.010-in. i.d.) tubing with molten K, and using a temperature gradient for controlled solidification. Four-terminal magnetoresistance measurements were made of the encapsulated K wires in transverse and longitudinal magnetic fields up to 44 kG. The search for the magneto-flicker noise was made up to 44-kG fields and 1.5-A d.c. currents. No magneto-flicker noise was found from 10 Hz to 10 kHz greater than or equal to 4 nV, which is the minimum detectable noise signal. The nonobservance of the magneto-flicker noise in the plastic-encapsulated samples of 0.023-in. i.d. indicates a discrepancy $\sim 10^6$ in the mean-square noise voltage of the magneto-flicker noise, as predicted by the original CDW model. An analysis of the data on the cupro-nickel-encapsulated samples of 0.010-in. i.d. indicates that the samples have voids with a total length $\sim 1\%$ of the sample length and thin K films (~ 1.5 μm thick) connecting the K regions separated by the voids. The nonobservance of the magneto-flicker noise in these thin films indicates a discrepancy $\sim 10^3$ in the mean-square noise voltage of the magneto-flicker noise, as predicted by the revised CDW model.

I. INTRODUCTION

The alkali metals, and in particular Na and K, should be among our simplest solids. As Lee[1] has noted, all direct evidence indicates that the Fermi surfaces ought to be closed and very nearly spherical. In particular, measurements by the de Haas-van Alphen technique indicate that the anisotropy of the Fermi surface of Na[2] is less than one part in 10^3 and that of K[3] is on the order of one part in 10^3. Therefore, a nearly free electron (NFE) model should be an excellent approximation to describe the electronic properties of these metals. Nevertheless, measurements of many of the electronic properties of the alkali metals cannot be adequately explained by an NFE model.

For example, the conduction-electron-spin resonance (CESR) has been measured in K by Walsh *et al.*[4]; the linewidths were found to split into two well-resolved components as the magnetic field was tilted away from an initial orientation parallel to the crystal surface. The free-electron model has no explanation for the splitting. Overhauser[5] has reported that similar results have been observed by Dunifer and Phillips. Furthermore, measurements of the electrical resistivity and ultrasonic attenuation of K from 2.5 °K to 20 °K made by Natale and Rudnick,[6] as analyzed by Rice and Sham,[7] show that the ratio of the relaxation times for the ultrasonic attenuation and electrical resistivity should be ~0.9, while the data indicated a ratio ~2.7—a large discrepancy between theory and experiment. (See also the theoretical work of Trofimenkoff and Ekin.[8])

The most persistent of the anomalous electronic properties in the alkali metals is the high-field magnetoresistance, hereafter designated MR. The theory of Lifschitz *et al.*,[9] which has been successful in explaining the high-field MR of most metals,[10] indicates that a metal with a spherical Fermi surface should have no MR and a metal with a closed, but nonspherical, Fermi surface should have a MR independent of the magnetic field for $\omega_c\tau \gg 1$, where ω_c is the cyclotron frequency and τ is the relaxation time at zero field. The alkali metals, according to this theory, should have a saturating MR at high fields, and Na and K should possibly have no MR at all. Yet measurements obtained by four-terminal,[11-13] helicon-resonance,[11,14] soft-helicon,[15] and eddy-current-torque[13,16,17] techniques in Na and K indicate a linear MR up to $\omega_c\tau \sim 300$, and the measurements of Simpson[15] show a much larger rise in the longitudinal MR than in the transverse MR and a longitudinal MR which varies with crystal orientation by a factor of 2.

The eddy-current-torque technique used by Schaefer and Marcus[16] in K not only indicates a linear MR, but also a large twofold anisotropy in the torque for all orientations of their samples, with a preferred direction being a [110] axis. This anisotropy is completely unexpected for K, which supposedly has cubic symmetry. Lass,[18] who has made induced-torque measurements[13] on one K sphere larger than those of Schaefer and Marcus, and had seen no anisotropy, has attributed the anisotropic results of Schaefer and Marcus to a 10% departure of the sample shape from sphericity.

Lass's explanation, however, appears to be untenable.[5,17]

Recently, the thermal MR of K has been measured by Newrock and Maxfield[19] and Fletcher.[20] One would expect the thermal MR to mirror the field dependence of the anomalous electrical MR if the anomalous electrical MR were due to spatial inhomogenieties as suggested by Babiskin and Siebenmann[21]; yet Newrock and Maxfield found a different field dependence, and their results still cannot be explained by the theory of Lifschitz *et al.*[9] Furthermore, Fletcher showed that his thermal MR data can be reduced as a function of temperature. His results indicate a large discrepancy with the theory of Ekin.[22]

Several attempts, one of which is the charge-density-wave (CDW) model developed by Overhauser,[5,23,24] have been made to explain the anomalous electronic transport properties of Na and K (see Falicov and Smith[25] for a short review of the various models). Whereas most of the models are difficult to test, the CDW model has recently been modified, in the light of the Schaefer-Marcus experiment, to a form which permits a new and unique test. Overhauser[5] has shown that the CDW model predicts a large magnetic-field-dependent flicker noise in long, thin wires of K or Na.

The following theoretical assumptions are basic to the CDW model in explaining the electronic transport properties of K and are relevant to the predicted magneto-flicker noise:

(i) Phasons, or low-frequency phononlike excitations of a CDW ground state must exist in order to contribute the necessary, large Debye-Waller factor needed to explain[24] why CDW satellites were not observed in a neutron diffraction experiment.

(ii) The phasons must fluctuate the $\vec{Q}'$ direction, or the direction of the cylinder axis of the "wedding band" in the CDW model, over an angular width ~45° to explain[25] the angular width in the induced-torque anomalies of Schaefer and Marcus.

(iii) $\vec{Q}$-domain sizes must be on the order of the sizes of the spheres used by Schaefer and Marcus, ~2–7mm, in order to explain[26] the induced-torque anomalies.

The following additional assumptions are required in the derivation of the magneto-flicker noise:

(iv) Successive resistance pulses from the same $\vec{Q}$ domain must be uncorrelated in time.

(v) The characteristic amplitude of the $\vec{Q}'$ oscillation must be finite [assumption (ii) implies that twice the amplitude should be ~45°].

(vi) The characteristic frequency ν of the $\vec{Q}'$ oscillation must be consistent with the condition $f \ll \omega_c \tau \nu$, where f is the frequency under observation, ω_c is the cyclotron frequency, and τ is the scattering time. (At $f = 10$ Hz and $\omega_c\tau = 10$, ν could be as low as 10 Hz.)

With these assumptions, Overhauser first predicted a magneto-flicker mean-square noise voltage $\langle V^2\rangle$ of the form[5]

$$\langle V^2\rangle = \frac{3\gamma\eta d S I^2 R_0^2(\omega_c\tau)^3}{2\pi^2 L}\,\frac{\Delta f}{f}\;; \qquad (1)$$

here γ is the $\vec{Q}$-domain shape parameter ~1, η is the fractional number of electrons enclosed by the heterodyne gaps and is ~0.10, d is the diameter of the K wire, S is the Kohler slope of the MR ($S \equiv \Delta\rho/\rho_0\omega_c\tau$, where ρ_0 is the zero-field resistivity, and $\Delta\rho$ the change in resistivity as a function of H), I is the wire current, R_0 is the zero-field resistance, L is the specimen length, Δf is the bandwidth, and f is the frequency of measurement. The term $(\omega_c\tau)^3$ indicates a field dependence of H^3, which could have provided a unique signature for the noise, different from microphonics.

After the results of the first part of this experiment (see Sec III) were communicated to Overhauser, the model was revised, and a new form proposed for the magneto-flicker noise[5]:

$$\langle V^2\rangle \approx \frac{a^3\omega_c\tau S I^2 R_0^2}{d^2 L}\,\frac{\Delta f}{f}\;; \qquad (2)$$

here a is the finite coherence length for the direction of $\vec{Q}'$ in a single $\vec{Q}$ domain. The new assumption was invoked that the phasons make the local direction of $\vec{Q}'$ vary within a single $\vec{Q}$ domain (i.e., spatial variations in the $\vec{Q}'$ direction as well as temporal fluctuations) so that the volume over which a flicker resistance occurs is no longer the volume of the entire $\vec{Q}$ domain, but a possibly much smaller volume, $(4\pi/3)a^3$, where a is defined to be some coherence length for $\vec{Q}'$, at least as large as the cyclotron radius of an electron in 30-kG field. Otherwise, the electron orbit would cut through areas where $\vec{Q}'$ has a different orientation, and a de Haas–van Alphen effect would not be observed at 30 kG.[27] Thus $a \gtrsim 2\times10^{-4}$ cm, the cyclotron radius at 30 kG.

In deriving Eq. (2), Overhauser[27] notes that the resistance volume $(4\pi/3)a^3$ is much smaller than the size of the samples used in observing a linear MR. Because of its small size, this volume will be short circuited as soon as its resistance in the field becomes a few times that of the other material, and the volume effectively becomes a void. Overhauser then invokes the current-jetting idea of Lass,[28] but for transverse fields—that at high field the current cannot bend around the void with a slope greater than $1/\omega_c\tau$. Thus, the effective volume which is shorted out is proportional to $\omega_c\tau$.

This field dependence of the effective volume will give rise to a linear MR, and with the fluctuations in the $\vec{Q}'$ direction, it will give rise to a magneto-flicker noise. By Eq. (2), the noise will have a different field dependence than originally calculated and will be smaller, by a factor a^3/d^3, because the relative volume over which $\vec{Q}'$ flickers is no longer proportional to d^3 (the size of a $\vec{Q}$ domain), but to a^3.

Since the predicted magneto-flicker noise is so critically connected to the CDW model, its observance or nonobservance is a crucial test of the validity of the model. As quoted from Overhauser[5]: "Experimental test of this prediction is crucial, since it may show that success can be a measure of ingenuity without being a measure of truth." The present experiment was undertaken, at Overhauser's suggestion, as such a "crucial" test of the CDW model.

II. EXPERIMENTAL METHODS

The following sample characteristics were desired: (i) a minimum wire diameter d, since the mean-square noise voltage $\langle V^2\rangle$ is expected to vary as $(1/d)^3$ for Overhauser's first theory or as $(1/d)^6$ for his second theory; (ii) a maximum wire length L, since $\langle V^2\rangle$ is expected to vary as L; (iii) flexible, encapsulated samples which can be wound in a bifilar configuration, since such a winding is essential to cancel microphonic noise due to the motion of the coiled sample in a high magnetic field; (iv) high-purity samples with a high mean collision time τ, since $\langle V^2\rangle$ is expected to vary as τ^3 for Overhauser's first theory or as τ for his second theory; (v) current and potential contacts which remain intact when the sample is cooled to 4.2 °K and recycled to room temperature, and which themselves produce no measurable $1/f$ noise due to current fluctuations at point contacts.

The samples were made out of K purchased from Leico Industries, Inc., with purity 99.95% and typical residual resistivity ratio (RRR) $\rho(293\,°\mathrm{K})/\rho(4.2\,°\mathrm{K}) \sim 6000$. The samples were prepared by degassing the high-purity K, vacuum filling long thin plastic (0.023-in. i.d.) or cupro-nickel (0.010-in. i.d.) tubing with molten K, and using a temperature gradient for controlled solidification. (Further details on sample preparation can be found elsewhere.[29]) The plastic tubing was made of transparent, irradiated shrinkable polyolefin, and the plastic-encapsulated samples showed no visible surface imperfections or voids. The nontransparent cupro-nickel (70/30) tubing was used for some samples, even though the sample surface condition could not be viewed, because it provided the smallest available inner diameter. The polyolefin tubing does react slowly with K if left at room temperature for over 4 h. As time progresses the color of the K surface changes several times until it becomes white. This surface reaction is completely inhibited by storage at liquid-nitrogen temperatures.

The vacuum-filling and gradient-cooling techniques in the sample preparation procedure provided a simple means for simultaneously forming excellent current and potential contacts in the polyolefin-encapsulated samples. The design of these contacts is shown in Fig. 1(a). A hole 1 mm in diameter was made in the polyolefin tubing wall, a Cu wire was wrapped around the tube near the hole, and a larger diameter polyolefin tube was slipped over the hole. As shown in Fig. 1(b), the outer tubing was shrunk down on its ends to seal against the inner tube. The hole for the Cu lead wire was then sealed with "5-minute" epoxy. When the sample tubing was vacuum filled, the molten K filled the entire volume around the Cu lead wire, thus forming a secure contact which would have no $1/f$ noise. When the sample was cooled by a temperature gradient, the K in the hole did not pull away, and thus the K-to-K-to-Cu contact remained. The K-to-K contact assured continued contact while the sample was cooled to helium temperature and recycled to room temperature. The current and potential contacts on the cupro-nickel tubing, which is essentially a conductor with RRR of 1, were made by soldering Cu wires directly onto the tubing with thermal-free solder before filling the tubes with potassium.

Since the room-temperature resistance per unit length of the cupro-nickel tubing is only a few times that of K, the room-temperature resistance of the K itself could not be measured directly for the cupro-nickel-encapsulated samples. Instead, the resistance was calculated using the measured

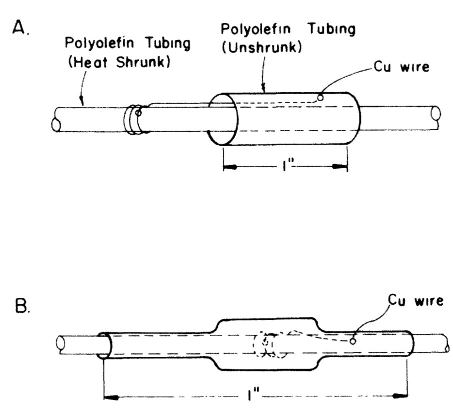

FIG. 1. Potential contacts.

length between the potential contacts, the diameter of the tubing given in the specifications, and an assumed resistivity[30] for K of 7.19 $\mu\Omega$ cm. The calculation was checked by measuring the resistance of the cupro-nickel tubing with and without the K, assuming that the K and cupro nickel were effectively parallel resistances.

At low temperatures the cupro-nickel tubing essentially acts as an insulator compared to the high-purity K. Nevertheless, if gaps occur in the K, the current could flow through the tubing and between adjacent turns of the bifilar sample. Because gaps could not be visually checked in the cupro-nickel tubing, the tubing was itself encapsulated in polyolefin shrinkable tubing (before making the sample), to avoid any possible short circuiting between adjacent turns. This precaution turned out to be very important later.

The final encapsulated wire samples produced had lengths between 2 and $3\frac{1}{2}$ ft., potential and current contacts separated by 2 in., and diameters of 0.023 in. (0.58 mm) for the polyolefin-encapsulated wires and 0.010 in. (0.25 mm) for the cupro-nickel-encapsulated wires. In bifilar wound coils, they had residual resistivity ratios of 5000–6000 for the plastic-encapsulated wires and 300–400 for the cupro-nickel-encapsulated wires. (This difference is discussed in Sec. III.)

The samples were mounted on coil forms designed for measuring the transverse MR or the longitudinal MR. Because of the bifilar winding for the transverse MR a small longitudinal component was contributed from the one bend in the tubing and from the pitch in the winding. In the winding for the longitudinal MR, a transverse component was contributed from a bend for each 3 in. of tubing; this design of winding was required to compare the longitudinal MR with the transverse MR for the same sample. For both forms stop cock grease was liberally applied around the sample and leads in order to provide a rigid coil and lead assembly at helium temperature. This procedure minimized microphonic noise and kept the leads from shorting to one another inside the helium Dewar, even in the presence of large magnetic fields.

The sample coil form was then lowered on a probe into a Varian superconducting solenoid and cooled to liquid-helium temperature using helium exchange gas. The temperature above the sample-coil form was monitored throughout the experiment using a calibrated Cryo Cal., Inc., Ge resistor in a low-frequency bridge circuit.

The dc MR was measured by the standard four-terminal technique. A Willard high-stability voltage cell was used as the current source, a Keithley 148 nanovoltmeter measured the potential difference across the sample, and a Dana digital voltmeter measured the potential difference across a standard 1-Ω Leeds and Northrup resistor in series with the sample. The current was varied with a slide wire resistor to determine if the sample resistance was Ohmic, and the current was reversed to check the zero on the nanovoltmeter. The magnetic field was also reversed to account for the Hall voltage; owing to the bifilar winding the Hall voltage was very small. The magnetic field was determined to sufficient accuracy by measuring the current through the superconducting solenoid and knowing the solenoid field constant. Magnetic fields up to 44 kG were obtained.

The measured dc MR of the plastic-encapsulated samples has an uncertainty due to the thermal-voltage drift over a single measurement period. To compensate, many measurements were taken at each magnetic field, but it was decided to measure the ac MR for greater accuracy. (Measurement of the ac MR of the cupro-nickel-encapsulated samples was not necessary, since their high resistances made the thermal-voltage drift negligible.) The four-terminal ac MR measurement system used a PAR HR-8 lock-in amplifier with a type-B preamp and a GR type-1309 oscillator for the ac current source and reference signal to the lock-in amplifier; the phase was adjusted to obviate measurement of the sample inductance. Measurements of the ac MR from 10 Hz to 10 kHz were consistent with the dc results.

The search for the magneto-flicker noise (see Fig. 2) was made using several variables. The dc current was varied from 0 to 1.5 A, the magnetic field from 0 to ±44 kG, the frequency from 10 Hz to 10 kHz, and the Q, $f/\Delta f$, of the amplifier from 5 to 25. The search was made in the transverse and longitudinal MR. Samples were re-

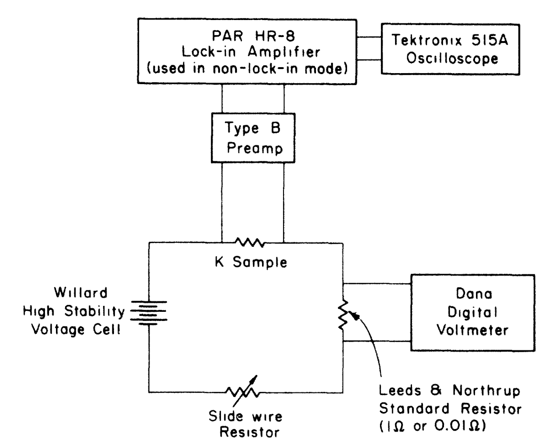

FIG. 2. Measurement system for magneto-flicker noise.

cycled between 4.2 and 77 °K, and 4.2 and 295 °K.

The minimum detectable noise signal was determined as follows, closely simulating the actual input impedance conditions employed for the sample noise measurements. A GR type-1390-B random-noise generator produced white noise or $1/f$ noise across a Cu wire (0.9 or 12 mΩ) and a GR decade resistor in series with Cu wire. The PAR HR-8, used in the non-lock-in mode with the type-B preamp, measured the noise across the Cu wire. To determine the actual noise signal produced by the noise generator for a Q of 10 on the HR-8, the type-B preamp was replaced by a type-D preamp, which has a high input impedance, and the HR-8 measured the rms noise voltage across the output of the noise generator with $Q=10$. Then with the same Q and the same output noise from the noise generator, the HR-8 with the type-B preamp measured the noise across the Cu wire. The minimum detectable noise signal was found to be 4 nV from 10 Hz to 10 kHz for a $Q=10$.

III. RESULTS AND DISCUSSION

A. Data on polyolefin-encapsulated samples

Two polyolefin-encapsulated samples were made with the characteristics listed in Table I; the MR curves for sample No. 2 are shown in Fig. 3. The MR data were taken with the dc current technique for sample No. 1 and with the ac current technique for sample No. 2 with both samples at 4.2 °K. The general form of the MR curves is similar to that found by others,[11] showing a monotonically increasing MR at high fields, with no evidence of saturation.

According to the original theory of magnetoflicker noise [Eq. (1)], the mean-square noise voltage was expected to be ~$(6\mu V)^2$ for sample No. 1 with $I=1A$, $\omega_c\tau=134$, and $\Delta f/f=0.1$. For the transverse MR of sample No. 2, the predicted value of $\langle V^2\rangle$ was $(4.7\mu V)^2$, at $\omega_c\tau=155$. No noise was seen in either sample greater than or equal to $(4\text{ nV})^2$ from 10 Hz to 10 kHz. This result was some six orders of magnitude below that predicted by Eq. (1).

TABLE I. Characteristics of polyolefin-encapsulated samples. The order in which the data were taken on sample No. 2 is left to right, increasing with time. T ≡ transverse MR. L ≡ longitudinal MR. R_0 ≡ resistance of the specimen at 4.2°K.

	Sample No. 1	Sample No. 2		
	T	T	L	T
Diameter d (in.)	0.023	0.023	0.023	0.023
Length (cm)	116	113	113	113
RRR	5300	5660	5580	5350
R_0 (μΩ)	57	51.7	52.5	54.6
S	0.0055	0.0025	0.012	0.0061

The samples were not annealed at room temperature for longer than 1–2 h, because of possible surface reaction with the polyolefin, although they were often stored for many days at liquid-nitrogen temperature prior to use. The samples remained intact as they were slowly cooled to liquid-helium temperature. In general, however, the polyolefin tubing broke apart in warming up to room temperature after a helium temperature run. This was true for all the preliminary samples and sample No. 1. Sample No. 2 was an exception, so that MR data could be taken with this specimen three times before it finally broke.

The MR curves indicate an initial negative MR changing into a linearly increasing MR with no significant "knee" in the MR as reported by Babiskin and Siebenmann[21] in polyolefin-encapsulated samples. The samples have a diameter ~ 0.6 mm so that an estimate of the size effect as the ratio of the electron mean free path l to the wire diameter d would be l/d ~ 30% for a RRR of ~ 6000. The negative MR for the samples reached 6 to 11% for the transverse MR and 17% for the longitudinal MR. Furthermore, the longitudinal MR remains negative to a much higher value of $\omega_c\tau$ than the transverse MR, and the Kohler slope is higher by a factor of about 2 to 4. The difference in the Kohler slope between the longitudinal and transverse MR is not as great as that reported by Simpson,[15] who reported differences of factors of ~ 20–40.

It should be noted that just before sample No. 2 was cooled for the transverse MR repeat, a crack in the tubing was noted, and the K at the crack had visibly oxidized. This fact may account for the small change in RRR from ~ 5600 to 5400 between

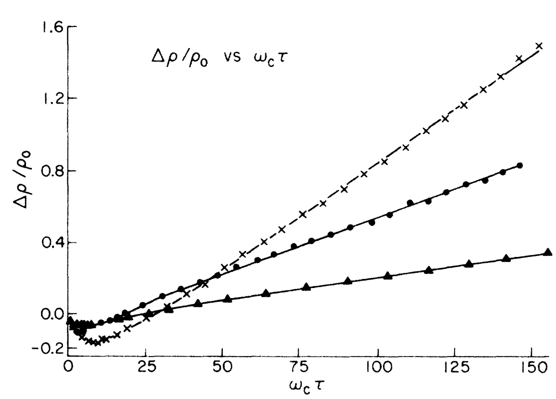

FIG. 3. $\Delta\rho/\rho_0$ vs $\omega_c\tau$ for sample No. 2 of the polyolefin-encapsulated samples. The data were taken in the following order: ▲–▲–▲, transverse $\Delta\rho/\rho_0$; ×–×–×, longitudinal $\Delta\rho/\rho_0$; ●–●–● transverse $\Delta\rho/\rho_0$.

the two runs; the ratio had not changed significantly between the first transverse MR measurement and the subsequent longitudinal MR measurement. As evident from Fig. 3, the repeat transverse MR showed a considerably higher Kohler slope than the first measurement on the same sample. The reason for this difference is not understood. It may or may not be due to the crack in the tubing since similar variations in repeat runs have often been reported by other workers.

B. Effect on the first theory of magneto-flicker noise

After being advised of the results of this part of the experiment, i.e., the discrepancy of 10^6 between theory and experiment, Overhauser[5,27] revised the model for the linear MR and the magneto-flicker noise in the manner discussed in the Introduction. The revision essentially involves adding two concepts: (i) a resistance void whose effective volume (due to current jetting) is proportional to the field H, and (ii) a correlation length $a \geq 2$ μm over which a resistance flicker will occur.

The revised expression [Eq. (2)] for the magneto-flicker noise predicts a noise below our minimum detectable threshold for the polyolefin-encapsulated wires. For example, Eq. (2) predicts for sample No. 1, $\langle V^2 \rangle \sim (0.077\ \text{nV})^2 \ll (4\ \text{nV})^2$. To test the second model, wires of smaller diameter were required.

C. Data on cupro-nickel-encapsulated samples

Four small-diameter cupro-nickel-encapsulated samples were made with the characteristics listed in Table II; the MR curves for sample No. 2 are shown in Figs. 4 and 5 (note that these are not Kohler plots). All data were taken at 4.2 °K. There are two immediate problems presented by these MR curves.

First, the cupro-nickel-encapsulated samples appear to have a RRR ten times smaller than expected. The $R_K(\text{room } T)/R_0$ ($R_0 = R_{\text{sample}}(4.2\ ^\circ\text{K})$), normally termed the residual resistivity ratio RRR, $\rho(239\ ^\circ\text{K})/\rho(4.2\ ^\circ\text{K})$, varies from ~ 300 to 400 for the four samples. The expected RRR, including the correction for the size effect for the small-diameter wires, should be ~ 4000. The K used for these samples was taken from the same batch as used for the polyolefin-encapsulated samples and they showed values of RRR ~ 5500.

The second immediate problem presented by the MR data is the negative longitudinal MR out to high fields ~ 40 kG. If the $\omega_c\tau$ scale is calculated by using a RRR ~ 300–400, then the longitudinal MR is negative out to only $\omega_c\tau \sim 10$, which might be explained as a size effect. Note that the longitudinal MR in the polyolefin-encapsulated sample

TABLE II. Characteristics of cupro-nickel-encapsulated samples. Data for each sample were taken in order as recorded. $T \equiv$ transverse MR. $L \equiv$ longitudinal MR. $R_0 \equiv$ resistance of the entire specimen at 4.2°K.

	Diameter d (in.)	Length L (cm)	R_K (293°K) (Ω)	R_0 (mΩ)	S	$R_K(203°\text{K})/R_0$
Sample No. 1						
T	0.010	108	1.53	3.97	0.08	386
T[a]	0.010	108	1.53	4.76	0.07	322
Sample No. 2						
T	0.010	118	1.67	4.57	0.10	366
L	0.010	118	1.67	4.57	0	366
T	0.010	118	1.67	4.64	0.12	360
L	0.010	118	1.67	4.63	0	361
L	0.010	118	1.67	4.66	0	359
Sample No. 3[b]						
T	0.010	112	1.59	5.03	0.07	316
Sample No. 4						
L	0.010	62	0.879	2.10	0	418
T	0.010	62	0.879	2.10	0.12	418
L	0.010	62	0.879	2.10	0	418

[a] Strained: The second T was measured after large currents ~ 5–8 A were run through the sample with a 44-kG field at the end of the data-taking for the first T, and there was no warm-up between the two T measurements. We believe the sample was strained, because R_0 changed from 3.97 to 4.76 mΩ while at 4.2°K.

[b] Sample No. 3 was annealed at room temperature for 25 h before cooling to liquid nitrogen.

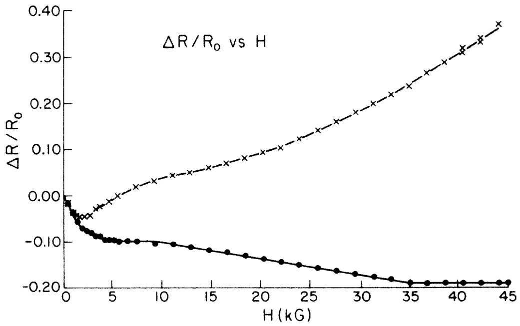

FIG. 4. $\Delta R/R_0$ vs H for sample No. 2 of the cupro-nickel-encapsulated samples. The data were taken in the following order: ×–×–×, transverse $\Delta R/R_0$; ●–●–●, longitudinal $\Delta R/R_0$. Further data from this sample are shown in Fig. 5.

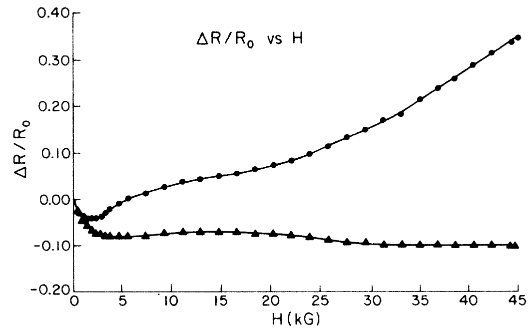

FIG. 5. $\Delta R/R_0$ vs H for sample No. 2 of the cupro-nickel-encapsulated samples. These data were taken after those of Fig. 4 on sample No. 2 in the following order: ●–●–●, transverse $\Delta R/R_0$; ▲–▲–▲, longitudinal $\Delta R/R_0$; ▲–▲–▲, repeat longitudinal $\Delta R/R_0$. (To take data for this repeat longitudinal $\Delta R/R_0$ the sample was slowly warmed up to room temperature, but not removed from the sample holder. It was then cooled slowly back to 4.2 °K for the measurement. The curves coincide.)

shown in Fig. 3 is more pronounced than the transverse MR in that sample and does not start its upward swing until $\omega_c\tau \sim 9$. Since the cupro-nickel-encapsulated samples are thinner one might expect the longitudinal MR minimum to occur at a higher $\omega_c\tau$. The RRR, however, still would remain ten times too small.

"Dirt," strains, or gaps in the potassium were among possible explanations for the low RRR. Dirt in the tubing was considered, but the method of making the samples precluded any likelihood of serious contamination, since a large volume (~ 20 to 70 times that of the sample) of liquid K was flushed through the cupro-nickel tubing before the sample was made. In addition, measurements[31] of the solubility of Ni in liquid K show that Ni from the tubing should be insoluble in the K at the temperatures used in making the samples. To test whether any possible diffusional contamination might occur, a sample was prepared and was held at room temperature for 25 h before testing; it showed the same RRR as other samples which had been stored at low temperature.

The low RRR could possibly be due to strains, but the strains would have to be extremely large. Gurney and Gugan,[32] who were interested in the annealing processes in deformed K, applied a maximum tensile stress of 5% to extruded wires at 4.2 °K. The RRR of the wires was lowered to ~$\frac{2}{3}$ of its original value (~ 5000) by this tensile stress. They also deformed the K wires by compression and defined "the equivalent tensile strain" for a compressive deformation which would produce the same resistivity increment in a specimen deformed by tension. For their largest compression, which was a 25% equivalent tensile strain, the RRR of the wires was lowered to ~$\frac{1}{3}$ of its original value. Thus, an extremely large tensile strain would be necessary in the cupro-nickel-encapsulated wires to lower the expected RRR of ~ 4000 to the observed RRR of ~ 300–400, i.e., a factor of $\frac{1}{10}$. Furthermore, the cupro-nickel tubing does not appear to wet the molten K. Thus, abnormally large strains would be unexpected.

It was originally thought that there were no gaps in the K, because the resistance contribution of the cupro nickel over even a small gap would lower the RRR too far and possibly mask any MR due to the K. The MR of the cupro-nickel tubing itself had been measured and found to be negative, ~ – 1.7% for the transverse MR and ~ – 1.9% for the longitudinal MR at 44 kG. Since the measured RRR of the sample No. 2, for example, was ~ 370, a gap in the K could not be larger than ~ 1 mm out of 118 cm. On the other hand, such a 1-mm gap would not contribute a large enough negative transverse MR at 44 kG to significantly alter the Kohler slope of the K.

Attempts were made to make samples in cupro-nickel tubing with different diameters. Two samples were made in 0.025-in.-i.d. tubing, $2\frac{1}{2}$ times the diameter of the data samples. When one sample was slowly cooled to liquid-helium temperature, it showed a RRR of ~ 200. The other sample was quenched to liquid-helium temperature and had a RRR of ~ 100. Three samples were made in 0.005-in.-i.d. cupro-nickel tubing, half of the diameter of the data samples. The first was quenched to liquid-helium temperature and had a RRR of ~ 150. The second was slowly cooled to liquid-helium temperature and had a RRR of ~ 30, less than the RRR of a "quenched" sample. This second 0.005-in.-i.d. sample was checked for any transverse MR, and none was observed up to the highest field. The third 0.005-in.-i.d. sample was slowly cooled to liquid-helium temperature and had a RRR of ~ 56. It had a negative transverse MR of ~ − 1% at full field, and showed no noise (to within 4 nV) at 10 Hz and 1 kHz. It seems likely that the two 0.005-in.-i.d. samples which were checked for MR had gaps in the K and that the other 0.005-in.-i.d. and the two 0.025-in.-i.d. samples probably also had gaps.

A simple test was devised to look for possible gaps in the 0.010-in.-i.d. samples (used for the data) at room temperature. This test was made after all the MR data had been taken, so that no samples were actually checked for gaps before taking MR data. Since a total gap size over 1 mm should have masked the observed transverse MR, the test had to be sensitive to very small gaps. Two parallel straight pins were separated by $1\frac{1}{2}$ mm and rigidly held in place by a nylon block. These pins were used as contacts to measure the potential over $1\frac{1}{2}$-mm increments of the cupro-nickel-encapsulated samples. A dc current was run through the sample, and a search for gaps was made by sliding the pins along the outside of the cupro-nickel tubing. Whenever there was a gap, the recorded potential would jump, because the resistance of the cupro nickel was higher than the parallel combination of the K and cupro nickel. The size of the gap could be estimated by considering the gap resistance in series with the parallel combination of K and cupro nickel over the $1\frac{1}{2}$ mm. Since the resistance of the empty and K-filled cupro-nickel tubing could be measured separately, the gap size could be calculated. Individual gaps were found up to $1\frac{1}{2}$ mm in length. The total sum of the gap lengths found were as follows: sample No. 1, ~ 13.5 mm; sample No. 2, ~ 14.6 mm; sample No. 3, ~ 12.9 mm; and sample No. 4, ~ 5.57 mm (sample No. 4 was about half the length of the others).

Although these gaps were measured only at room temperature they should also exist at liquid-helium temperature, since Schouten's[33] thermal-expansion data for K show a thermal-expansion coefficient several times that of L-nickel,[34] which is a good approximation to cupro nickel. (It should be recalled that the cupro-nickel-encapsulated samples were insulated by being encapsulated in polyolefin tubing so that there was no possible short-circuiting between adjacent coil turns at a gap; thus the MR data are still valid.) Clearly a specimen with complete gaps of total length $\gg 1$ mm could not have shown the large measured positive transverse MR, nor even a value for the RRR greater than 100. The only consistent explanation is that the "gaps" noted at room temperature are not, in fact, complete, but are at least partially bridged by thin films or filaments of K.

Consider that the gaps are not really complete but are large voids with a K film that still connects the separate regions of the K wire together. For simplicity consider that the gap is bridged by a cylindrical film of length l_0 and thickness δ. We may easily estimate the thickness δ of the film between the void and the cupro nickel to satisfy the following conditions:

(i) At room temperature, the resistance of the K film is much greater than the resistance of the cupro-nickel tubing over the length l_0 so that the current travels only through the cupro nickel over l_0. (The 1.5-mm gaps that have been found indicate no measurable resistance contribution from a K film at room temperature.)

(ii) At liquid-helium temperature, the resistance of the K film is much less than that of the cupro-nickel tubing over l_0 so that the current travels only through the K film over l_0. (This is necessary to explain the observed positive transverse MR.)

(iii) RRR of the samples ~ 300 − 400.

(iv) The longitudinal MR is negative to fields of over 40 kG.

Condition (i) can be met if the film thickness is 1 − 2 μm or less. Condition (ii) can be met if the film thickness is between 1 and 2 μm, remembering that the size effect becomes very important at 4.2 °K. Condition (iii) is met by calculating the total resistance at 4.2 °K for a K wire (RRR of ~ 4000 including the size effect for a diameter of 0.010 in.) over almost the entire sample length plus the total resistance of the film over the lengths of all the voids in the wire. Using measured values of RRR the following values of the film thickness δ were calculated: sample No. 1, $\delta \sim 1.6$ μm; sample No. 2, $\delta \sim 1.5$ μm; sample No. 3, $\delta \sim 1.3$ μm; and sample No. 4, $\delta \sim 1.4$ μm. Evidently, conditions (i)–(iii) are met by a film thickness which can vary between ~ 1.3 and 1.6 μm from sample to sample. Condition (iv) can now readily be explained, since the observed resistance is largely due (~ 90%) to the K in the films around the voids. However, since the RRR of the K in the films is only ~ 190 − 220 (due to the size effect), the effective value of $\omega_c \tau$ is only ~ 5 at 40 kG. A negative longitudinal MR at $\omega_c \tau \sim 5$ is entirely consistent with the results found for the thicker polyolefin-encapsulated wires.

Since the resistance change with field is due to two sections of K with different RRR, and thus different values for $\omega_c \tau$, a true Kohler slope cannot be given. However, because the K films dominate the resistance, approximate Kohler slopes can be estimated for the transverse MR curves, and these are listed in Table II.

Since it cannot be determined exactly what shape the voids take in the cupro nickel, a definitive statement about expected size effects in the MR cannot be made. One sample was cut open where there was a measured void, and the tubing appeared empty. The inside surface could not be inspected because of the small inner diameter of the tubing. The sample was also cut open where there was no measured void, and the K had completely filled the tubing as expected.

D. Effect on the second theory of magneto-flicker noise

Overhauser's derivation[27] of Eq. (2), expressing the magneto-flicker noise according to the revised theory, was made for cylindrical wires. The K around the voids here is approximated by a thin film (thickness $\delta \lesssim 2\ \mu$m) in the form of a large cylindrical tube (radius $r_0 \sim 125\ \mu$m). The geometrical considerations in his derivation have to do with the ratio of the cross-sectional areas of the wire and the field-dependent flicker volume when viewed longitudinally, $\sim (\pi d^2/4)/\pi a^2$. For the case of a thin film in the form of a cylinder this factor may be replaced by $2\pi\delta r_0/\pi a^2$. For the thin film around the voids Eq. (2) is replaced by

$$\langle V^2\rangle \approx \frac{a^3}{8\delta r_0 L}\,\omega_c\tau I^2 R_0^2 S\,\frac{\Delta f}{f}\,, \tag{3}$$

where now L, R_0, $\omega_c\tau$, and S refer to the K around the void. The total number of voids in the cupro-nickel-encapsulated samples varies from 8 to 20. The noise from each void in one sample will be uncorrelated with that from other voids, so that the total predicted magneto-flicker noise for a sample will be

$$\langle V^2\rangle = \sum_{i,\,\text{voids}} \langle V_i\rangle^2 = \sum_i \frac{a^3}{8\delta r_{0i} L_i}(\omega_c\tau)_i\, I^2 R_{0i}^2 S_i\,\frac{\Delta f}{f}\,.$$

Approximating each void by the same characteristics except for varying length and resistance gives

$$\langle V^2\rangle = \sum_i \frac{a^3}{8\delta r_0 L_i}(\omega_c\tau) I^2 R_{0i}^2 S\,\frac{\Delta f}{f} = \frac{a^3}{8\delta r_0}(\omega_c\tau) I^2 S\,\frac{\Delta f}{f}\sum_i \frac{R_{0i}^2}{L_i}\,.$$

But it is easily shown that $\sum_i (R_{0i}^2/L_i) = R_0/L$, where R_0 is the total resistance of the voids and L is the total length of the voids.

Therefore, the magneto-flicker noise for all the voids in one sample will be given by Eq. (3), with R_0 the total resistance of the voids and L the total length of the voids. This predicted noise from the films will dominate the noise from the K in the rest of the wire. Table III gives estimates for $\langle V^2\rangle$ for the four samples, with the following values for the common parameters: $a \approx 2\ \mu$m, $\omega_c\tau \approx 5$, $r_0 \approx 125\ \mu$m, and $\Delta f/f \approx 0.1$.

No magneto-flicker noise was observed in these samples $\gtrsim (4\text{ nV})^2$ from 10 Hz to 10 kKz. There is, therefore, a discrepancy of about three orders of magnitude in $\langle V^2\rangle$ with the revised theory of the magneto-flicker noise. This value for the discrepancy is found on the presumption that the correlation length a has its minimum possible value ($a = 2\ \mu$m) consistent with the CDW model explanation for the high-field de Haas–van Alphen experiment. The discrepancy is clearly worse for any larger value of the correlation length.

E. Review of assumptions

In trying to understand this difference of 10^3 between theory and experiment, it is beneficial to review all assumptions made both in the experimental analysis and in Overhauser's theory. In order to understand the MR curves, the RRR data, and the sample gaps or voids at room temperature a model was used which presumed thin K films around voids in the samples. Assumption of a film thickness ~ 1.3 to 1.6 μm consistently explained all the observations while other possible explanations (e.g., strain, impurities, or complete gaps) were entirely unsatisfactory. The film

TABLE III. Estimates for $\langle V^2\rangle$ for the four cupro-nickel-encapsulated samples.

	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
δ (μm)	1.6	1.49	1.33	1.37
L (cm)	1.35	146	1.29	0.557
R_0 (mΩ)	3.59	4.21	4.62	1.88
S	0.08	0.10	0.07	0.12
I (A)	1.5	1	1	1
$\langle V^2\rangle$ (nV)^2	$\approx (290)^2$	$\approx (225)^2$	$\approx (245)^2$	$\approx (190)^2$

thickness calculated is very sensitive to the measured values of RRR, MR, and total length of voids, and, as a parameter in this model, can vary only slightly to provide a consistent explanation for all the data. The actual geometry could, of course, be different from that assumed for a cylindrical void with a complete surrounding film. The void might well form with a film on only part of the surface, or possibly with the film being a very thin wire down the middle of the tube. Such variations do not appear to provide any substantive reduction of the calculable discrepancy. In fact, if the film were really in the form of a thin wire ~ 20 μm in diameter stretched across the void, the MR curves, RRR data, and the room-temperature "gaps" could still be explained, but such wires would have a RRR ~ 700 so that $\omega_c\tau$ would reach ~ 15. Under these conditions the magneto-flicker noise should be ~(1000 nV)^2 rather than ~(200 nV)^2. Any other imagined construction for the voids would have a predicted noise somewhere between these two ideal constructions.

In calculating the predicted noise from the data, many of the void characteristics were assumed to be constant for all the voids in the same sample: δ_i, r_{0i}, $(\omega_c\tau)_i$, and S_i were assumed to be the same for each separate void. This approximation seems to make little difference; indeed, if the cylindrical-film model does produce the least amount of noise for a void model, then setting δ_i, r_{0i} and $(\omega_c\tau)_i$ (effectively the RRR$_i$) constant actually sets a lower limit for the predicted noise. The approximation of setting S_i constant is more difficult to assess. The actual Kohler slope S of the sample must be some kind of average over the voids and the wire; the variance cannot be determined, but all four samples have similar Kohler slopes, which indirectly suggests that the variance over the voids is not very large. There may be a large difference in the Kohler slopes of the void K and the wire K, but that is not too important since the resistance and noise of the void K should dominate.

The size-effect corrections for the wires and the films were taken from Dingle's calculations.[35] The size-effect correction for the wire may be off 10–20%, but the difference is not crucial, because this size effect is only used to guess how much resistance should be in the voids to obtain the appropriate value for $R_K(\text{room } T)/R_{\text{sample}}(4.2\,^\circ\text{K})$. A 20% error in the resistance of the wire only contributes a 2% error in the void resistance, which is used to calculate the film thickness.

Another assumption was made in estimating the Kohler slope for the K films. For example, in sample No. 2, $S \sim \Delta R/R_0\omega_c\tau \sim 0.105$ in the linear part. In using a value $S \sim 0.105$ to calculate the predicted noise for the K films, it was implicitly assumed that both ΔR and R_0 were entirely due to the K films. Since $R_{\text{void}} \sim (90\%)R_0$, it is reasonable to assume $R_0 \sim R_{\text{void}}$. But assuming $\Delta R \sim \Delta R_{\text{void}}$ may be questionable. The following analysis helps to decide this point.

Since the measured longitudinal MR is still negative out to $\gtrsim 40$ kG, the longitudinal ΔR_{wire} cannot be larger than the longitudinal ΔR_{void}. (The longitudinal ΔR_{wire} must be positive, otherwise there is an extremely anomalous negative longitudinal MR out to $\omega_c\tau \sim 100$, since the RRR ~ 4000 for the K in the wire.) If the longitudinal ΔR_{wire} is equal and opposite to the longitudinal ΔR_{void}, then there would be a flat longitudinal MR at 40 kG as observed. One would expect the relative contribution to the transverse MR to be about the same, so we may consider the extreme case if the (transverse ΔR_{wire}) ~ (transverse ΔR_{void}). Then, using values for the field of 33 and 44 kG and the RRR of ~ 4000, we find the Kohler slope of the K in the wire would be 0.026, which seems large, but possible. This indicates that the Kohler slope for the K in the films would be 0.056. In other words, if there is a large change in resistance due to the K in the wire, the Kohler slope that should be used to calculate the predicted noise from the films is smaller by a factor of 2 than that actually used. However, the Kohler slopes of the K in the polyolefin-encapsulated samples were found to be $2\times10^{-3}-6\times10^{-3}$. One might expect that the K in the smallest-diameter cupro-nickel-encapsulated wires (smaller by a factor of 2.3 in diameter) would have similar Kohler slopes. Taub *et al.*[11] show four unannealed samples which were made from the same batch of K with diameters varying from 1.2 to 2.2 mm, and RRR's from 2440 to 3130, and with Kohler slopes varying from 1.7×10^{-3} to 4.4×10^{-3}, all in the same range. It therefore seems far more likely that the K in the wire part of the cupro-nickel-encapsulated samples would have a Kohler slope in the range ~2×10^{-3} to 6×10^{-3} rather than 26×10^{-3}. Then the Kohler slope S used in calculating the predicted noise from the films is only at most 10% too high. But even this difference is canceled, since in calculating $S \sim \Delta R/R_0\omega_c\tau$, R_0 was used instead of $R_{\text{void}} \sim (90\%)R_0$. Thus, considering all the evidence, the value actually used for the Kohler slope is probably correct.

The model used here to analyze the MR data indicates that the Kohler slopes for the K in the films is ~ 0.07 to 0.12. Such Kohler slopes are somewhat higher than generally reported in K wires of a much greater thickness. To our knowledge no MR data have been reported to date on K or Na specimens of comparable size and $\omega_c\tau$, so that the higher Kohler slopes may be due to some kind of a size effect. (It is interesting to note that if Overhauser's MR theory were correct, the Kohler slope would be larger when the dimensions of the specimen approach the $\vec{Q}'$-domain size, for this would reduce any short-circuiting effects.)

One assumption which should be made clear is that the equation for the revised magneto-flicker noise has been assumed to be true for $\omega_c\tau \sim 5$. This equation was, in fact, derived for the case $\omega_c\tau \gg 1$. Some kind of magnetic-field-dependent noise is inherent in the idea of the CDW model regardless of the field strength, because the fluctuating $\vec{Q}'$ should always produce a noise which will monotonically increase with field. How fast the noise should fall off as $\omega_c\tau$ is lowered below $\omega_c\tau \gg 1$ is not really known; however, one would not expect any sharp drop.

Furthermore, Overhauser's revised theory has been assumed true for films with thickness $\sim 1\frac{1}{2}$ μm. There may be problems in this assumption. In the derivation[27] of the revised theory, the conductivity of a wire whose dimensions were much larger than the flicker volume $(4\pi/3)a^3$ was calculated using an expression by Landauer[36] for a mixed media of two different conductivities. Landauer's expression strictly assumes an infinite conducting medium, i.e., no boundary effects. Overhauser uses this expression to show that the flicker volume $(4\pi/3)a^3$ will be effectively a void when the change in the resistivity of the flicker volume $\Delta\rho/\rho_0 \gtrsim \frac{3}{2}$. This number, $\Delta\rho/\rho_0 \gtrsim \frac{3}{2}$, enters indirectly into the noise equation, and, as the number is increased, the noise $\langle V^2\rangle$ decreases as 1/(the number). For $1\frac{1}{2}$-μm films, there may be important boundary effects in comparison to the flicker dimension $a = 2\mu$. However, it seems inevitable that at some value of $\Delta\rho/\rho_0$ of the flicker resistivity, the flicker volume will still effectively become a void. The numerical factor which applies, however, might be larger than $\frac{3}{2}$.

Another problem concerned with the small film thickness is the assumption that the current-jetting effect proposed by Lass[13] is appropriate to the thin-film case. Lass also assumed an infinite conducting medium in his derivation, and only attempted to apply current jetting when the void diameter was much less than the size of the sample and greater than the electron mean free path. Overhauser's assumed void diameters (~ 2 μm) are not, in fact, much less than the calculated thickness of our films (~ 1.6 μm), and the electron mean free path is restricted radially to ~ 2 μm. One might still expect some field dependence in current jetting (perhaps more complicated than just $\omega_c\tau$, when $\omega_c\tau \gg 1$) due to the other two dimensions in the film which are effectively much larger than the void diameter.

It should be noted that if there are, for some reason, no voids at 4.2 °K and the low RRR is due to some phenomenon other than thin films (i.e., unexpected strain or an unknown effect), then the revised theory of magneto-flicker noise still has a discrepancy ~ 10. With no films and a RRR of ~ 300–400, the value for $\omega_c\tau$ at high field is ~ 10. The Kohler slopes are correct, and there are no boundary effects to complicate the analysis. The predicted magneto-flicker noise then is $\sim (14\text{ nV})^2$ and was not seen to within $(4\text{ nV})^2$.

There seem to be serious limitations in ways in which the CDW model could be modified to accommodate the nonobservance of the magneto-flicker noise. The parameter a, which was defined to be a coherence length for the direction of $\vec{Q}'$, cannot be lowered below 2 μm without conflicting with de Haas–van Alphen observations at 30 kG.

It might be possible with spatial variations in the direction of $\vec{Q}'$ alone (no temporal fluctuations) to explain the nonobservance of magneto-flicker noise, the Schaefer-Marcus torque anomaly, and the linear MR. However, the phasons must fluctuate randomly in time to contribute to the Debye-Waller factor, if the CDW model is to explain why CDW satellites were not observed in neutron diffraction experiments. In fact, the phason frequencies assumed in calculating the Debye-Waller factor were approximately those of phonons.[23] These phasons must then cause the direction of $\vec{Q}'$ to fluctuate randomly in time, which will inevitably give rise to the predicted magneto-flicker noise. Furthermore, for the magneto-flicker noise to exist, it was only assumed that the characteristic frequency ν of the $\vec{Q}'$ direction was large enough so that $f \ll \omega_c\tau\nu$ and the characteristic amplitude of the $\vec{Q}'$ direction was finite. Both of these assumptions are also basic to explaining the neutron diffraction experiment. Thus, the CDW model inevitably must predict an unobserved magneto-flicker noise.

IV. CONCLUSION

The predicted magneto-flicker noise, according to Overhauser's original theory and revised theory, has not been observed. The original theory predicts $\langle V^2\rangle \sim (6\ \mu\text{V})^2$ at $\omega_c\tau \sim 134$ in the polyolefin-encapsulated samples, and no noise was found within limits of $(4\text{ nV})^2$ from 10 Hz to 10 kHz. This is a discrepancy of $\sim 10^6$ in the value for $\langle V^2\rangle$ predicted. The revised theory predicts $\langle V^2\rangle \gtrsim (290\text{ nV})^2$ at $\omega_c\tau \sim 5$ for the cupro-nickel-encapsulated samples, and no noise was detected to within $(4\text{ nV})^2$ from 10 Hz to 10 kHz. This is a discrepancy $\sim 10^3$ in the value for $\langle V^2\rangle$ for the noise signal predicted by the revised theory. With the possible exception of unknown boundary effects, no adequate explanation has been found for the discrepancy in the revised theory.

Recent work by Wilson *et al.*[37] indicates that there may be a charge-density wave in metallic, layered, transition-metal dichalcogenides. The Fermi surfaces of these materials are far more complicated than those of Na and K, but there should be a similar phason-induced magneto-flicker noise present. Such noise may be smaller than that predicted in Na and K because the phasons apparently do not produce such a large Debye-Waller factor as to obviate observations of the CDW satellites by neutron diffraction in these dichalcogenides. The functional dependence of the noise will probably also be far more complicated. One might look, however, for a field-dependent noise, and if found, such a noise would support the idea of a CDW in those materials.

ACKNOWLEDGMENTS

The authors are very grateful to Professor A. W. Overhauser for his stimulating theoretical comments and discussions. We also express our gratitude for the invaluable suggestions on sample preparation by Dr. S. A. Werner and Dr. J. Babiskin.

†Work supported in part by the U. S. Atomic Energy Commission under Contract No. AT(11-1)-1198.

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