HELICON RESONANCES IN NIOBIUM NEAR H_{c2}†

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In a recent Letter, Caroli and Maki[1] calculate the low-frequency ($\omega \ll kT_c/h$) electromagnetic response for a pure type-II superconductor in the vicinity of H_{c2}. In particular, when the oscillating currents are in a plane perpendicular to the static external magnetic field H_0, the imaginary part of conductivity vanishes to order $H_{c2}-H_0$. As a consequence of this, they find that the helicon resonant frequency in the mixed state just below H_{c2} should be the normal-state value at H_{c2} scaled by an appropriate field- and temperature-dependent carrier density, N_n.

Caroli and Maki[1] suggest that a precise determination of the helicon frequency in the vicinity of H_{c2} would be a direct check of their theory. We have determined the field dependence of the helicon resonant frequency near H_{c2} in a very pure, strain-free sample of Nb[2] having a residual-resistance ratio of about 11 000. The field dependence near H_{c2} is much different from that reported previously,[3] probably because strains that were introduced by spark cutting are no longer present. The experimental results are shown in Fig. 1. Both the field and frequency scales are expanded to show the detailed field dependence near H_{c2}. There is no discontinuity in ν_r, but there appears to be a discontinuity in the slope of ν_r vs H_0.

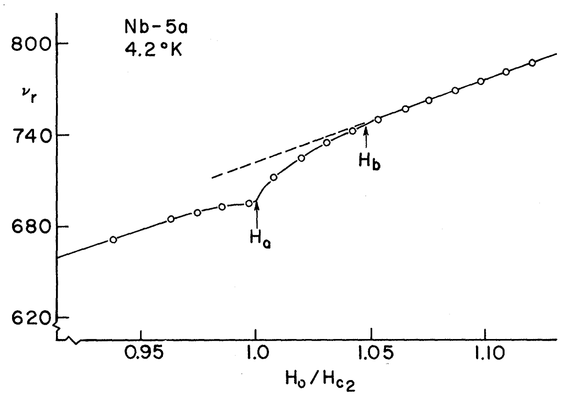

FIG. 1. The field dependence of the helicon resonant frequency in niobium near H_{c2}. Both scales are expanded. The niobium sample is a flat plate 0.3 mm × 4 mm × 35 mm having a resistance ratio of 11 000. The dashed line shows the extrapolated normal-state helicon resonant frequency. $H_a = H_{c2} = 2630$ G and $H_b = 2750$ G.

On close examination there appear to be two "critical" fields. These are shown in Fig. 1 by arrows labeled H_a and H_b. At the lower field, H_a, there is a sharp change in the slope of ν_r vs H_0. This field corresponds to H_{c2} obtained by others from magnetization measurements.[4] Between H_a and H_b the resonant frequency changes gradually to the extrapolated normal-state value. The helicon-resonance amplitude reaches the normal-state value at H_a. Neither the resonant frequency nor the amplitude show any hysteresis.

To examine the region between H_a and H_b more closely, we determined the field dependence of the surface impedance using a marginal oscillator.[5] The results are shown in Fig. 2. As expected, the surface resistance[6] is almost linear in H_0 well below H_{c2}. However, in the vicinity of H_{c2} the surface resistance changes more rapidly, but it does not reach the normal-state value until H_b. The field dependence of the surface reactance shows similar behavior near H_{c2}.

We can offer no explanation of the behavior in the region between H_a and H_b but, since it is above H_{c2}, it may be associated with surface superconductivity. Our flat plate sample was accurately (within $\frac{1}{4}°$) perpendicular to the applied field; so the usual surface superconductivity[7] should be absent. If the transi-

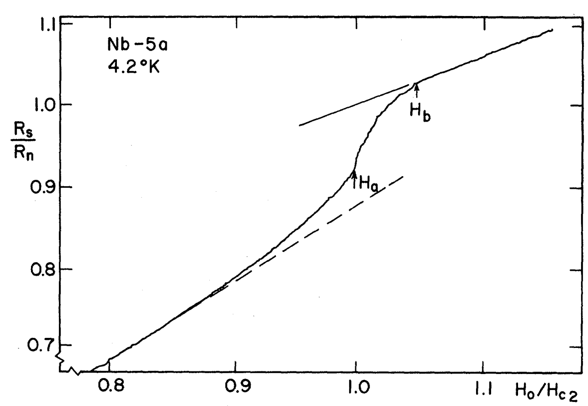

FIG. 2. The field dependence of the surface resistance near H_{c2} at 680 kHz for the same sample shown in Fig. 1. Both scales are expanded. The dashed line is the extrapolated linear surface resistance in the mixed state and the solid line is the extrapolated normal-state resistance.

tion region were not present, it appears that the mixed-state helicon resonance would change rather rapidly to the normal-state value. This is the behavior expected at low frequencies from the work of Caroli and Maki.[1] Because of the presence of the transition region, attempting a fit to their theory does not seem reasonable.

We are extremely grateful to Dr. R. W. Meyerhoff and the Union Carbide Corporation for supplying us with the niobium samples used in this investigation. Discussions with J. W. Wilkins have been very helpful.

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[1]Christiane Caroli and Kazumi Maki, Phys. Rev. Letters 18, 698 (1967).

[2]Dr. R. W. Meyerhoff prepared the niobium sample used in this investigation. The material is Union Carbide electrolytic niobium that has been rolled into a strip and then annealed and outgassed about 100°C below the melting point in a vacuum of 10^{-10} Torr. Heating was accomplished by passing a current through the niobium. A section of the annealed strip was used for these experiments.

[3]B. W. Maxfield and E. F. Johnson, Phys. Rev. Letters 16, 652 (1966).

[4]T. McConville and B. Serin, Phys. Rev. 140, A1169 (1965).

[5]In a marginal oscillator, a change in the shunt resistance (in this experiment, the surface resistance) of the tank circuit shows up as a change in the oscillator output. Marginal oscillators are discussed by E. R. Andrew, Nuclear Magnetic Resonance (Cambridge University Press, London, England, 1958), p. 49.

[6]B. Rosenblum and M. Cardona, Phys. Rev. Letters 12, 657 (1964).

[7]R. W. Rollins and J. Silcox, Phys. Rev. 155, 404 (1967). This paper gives a good discussion of surface superconductivity.

MÖSSBAUER STUDY OF FERRIMAGNETIC ORDERING IN NICKEL FERRITE AND CHROMIUM-SUBSTITUTED NICKEL FERRITE

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Mössbauer-effect measurements in external magnetic fields show that the magnetic structure of ferrimagnetic $NiFe_2O_4$ is the collinear Néel type. $NiFe_{0.3}Cr_{1.7}O_4$ is shown to have a triangular structure with $\theta_A = 20 \pm 10°$ and $\theta_B = 50 \pm 4°$.

In a recent Letter,[1] Kedem and Rothem have presented Mössbauer data which they propose is evidence for a Yafet-Kittel triangular spin arrangement[2] in the ferrimagnetic spinel $NiFe_2O_4$. Their conclusions are in sharp disagreement with the results of susceptibility measurements by Jacobs,[3] who proposed a Néel collinear model[4] for this material. We report here Mössbauer measurements in external magnetic fields which provide conclusive evidence for the Néel model and thus support the conclusions drawn by Jacobs. In addition, we show that the chromium substituted ferrite $NiFe_{0.3}Cr_{1.7}O_4$ is consistent with a Yafet-Kittel model.

Many of the magnetic properties of the ferrimagnetic spinel compounds $M^{2+}N_2^{3+}O_4$ are well understood on the basis of the Néel collinear model. However, for spinels with large amounts of chromium, the spontaneous magnetization is lower than the expected from this model and is usually interpreted in terms of the Yafet-Kittel triangular arrangement in which each tetrahedral A and octahedral B sublattice is divided into two sub-sublattices; the resultant moments of the two triangular sublattices are antiparallel. Experimental evidence for the Yafet-Kittel model has been established by high-field susceptibility measurements[3,5] and neutron-diffraction experiments.[6,7] Previous nmr[8] and Mössbauer[9,10] studies of $NiFe_2O_4$ indicate two different hyperfine fields, corresponding to the iron ions on the A sites and the B sites. However, Kedem and Rothem[1] have concluded, mainly from the width of the Mössbauer lines, that there are four hyperfine fields and that this observation constituted experimental evidence for the Yafet-Kittel model.

Our samples were made by firing mixed oxides including Fe_2O_3 enriched in Fe^{57} in a platinum crucible at 1200°C in air for ten hours; the resulting product was then ground to a pow-