OBSERVATIONS OF THE ESTABLISHMENT OF THE QUANTIZED FLUX STATE IN TIMES AS SHORT AS 10^{-5} sec*

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Deaver and Fairbank[1] have observed that when a hollow superconducting cylinder is cooled below its transition temperature in the presence of an external axial magnetic field, the flux in the cylinder changes to the nearest quantized unit, $n(hc/2e) = n \times 2.07 \times 10^{-7}$ G-cm^2. When the external field is turned off the same quantized fluxoid is maintained by a persistant current. Doll and Näbauer[2] also observed independently that flux maintained by persistent currents in the absence of an external field is quantized.

An important question arises as to the time required for the flux to change to a quantized value. Mercereau and Vant-Hull[3] measured the flux change occurring in a 1-mm diameter indium loop which was thermally switched between the normal and superconducting state at 6 kcps in an applied magnetic field. They looked for a periodic variation of the flux change as a function of the applied field, but found no observable quantized effect.

We have observed the flux change occurring in small, hollow tin cylinders cyclically cooled through the transition temperature in an applied axial magnetic field at frequencies up to 55 kcps. A periodic variation as a function of applied field was found at all frequencies tried, indicating that quantized flux is established in these cylinders at least as fast as 10^{-5} sec. We have measured the period and find it to be $hc/2e$ to within our experimental error of 3%.

Measurements were made on two tin cylinders each 1 cm long; the first was about 40 microns o.d. with walls roughly 500 Å thick, the second $47 \pm \frac{1}{2}$ microns o.d. with walls approximately 5000 Å thick. These were prepared by evaporation onto an insulated coaxial heater consisting of a thin copper-gold alloy film deposited on an enameled copper wire and shorted to the wire at one end.

The superconducting cylinder was cyclically heated above the transition temperature by passing an alternating current through the gold-copper film. The flux change occurring as the cylinder changed between the normal and superconducting state in an applied axial magnetic field was detected with a pickup coil wound closely around the cylinder. The voltage induced in the pickup coil at twice the frequency of the heating current was observed with a phase-sensitive detector and plotted as a function of the applied field on an X-Y recorder.

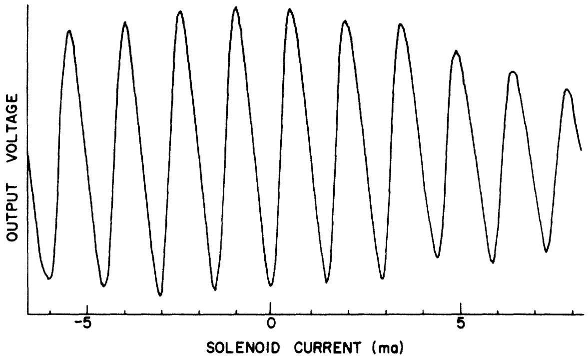

FIG. 1. Data for cylinder 1 taken at 7000 cps (3500 cps heating current) with an integration time of 1 sec and the current swept in 15 min. Neither the applied field nor the dimensions of the sample were known precisely, but the period is consistent with $hc/2e$ within the estimated 30% uncertainty in these quantities.

At low heating power the output from the pickup coil was proportional to the applied field. At higher heating power the output became periodic in the field. At still higher power the output was independent of the field indicating that the cylinder remained completely normal. The amplitude of the periodic signal was strongly dependent on the heating power and the bath temperature; consequently it was not feasible to calibrate the signal voltage directly in magnetic flux for these experiments. On the other hand, the period was independent of these variables.

Measurements were made at numerous frequencies from a few hundred cps up to 55kcps. In all cases the outputs were similar to those shown in Figs. 1 and 2. The output voltage was plotted continuously up to 40 periods from zero magnetic field.

The period determined for cylinder 2 is 11.6 milligauss corresponding to a flux through the entire cross section of the cylinder of 2.05×10^{-7} gauss cm^2 with a total estimated error of 3%.

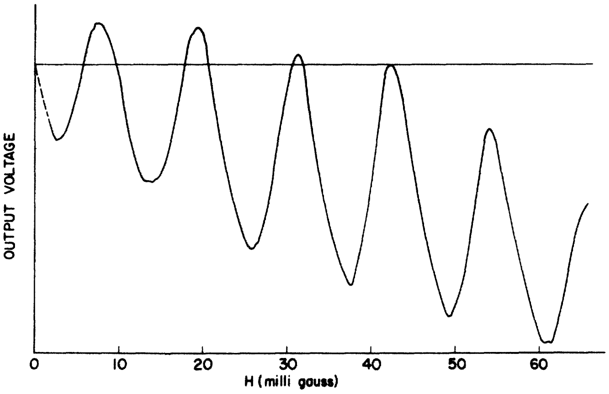

FIG. 2. Data for cylinder 2 taken at 10 000 cps with 3 sec integration time and 14 min field sweep. The average slope of the curve is attributed to the Meissner effect of the walls of this cylinder which were approximately ten times thicker than those of cylinder 1.

Since the voltage across the pickup coil is proportional to the flux change occurring as the cylinder becomes superconducting in the presence of the magnetic field, it can be interpreted as a measure of the equilibrium magnetization of the cylinder in the presence of the field. These magnetization data correspond to the point-by-point magnetization measurements of the original experiments of Deaver and Fairbank[1] in which both the magnetization and the trapped flux were found to be periodic functions of the applied field with period $hc/2e$.

When the cylinder is cooled through its superconducting transition temperature in the presence of a magnetic field, a current is induced in the walls to achieve the nearest integral number of quanta within the cylinder. Thus, when the cylinder is cooled in an applied field producing less than one-half flux unit within it, the cylinder acts as a perfect diamagnet expelling all the flux within it. For a value of applied field producing approximately one-half flux unit within the cylinder a sudden transition is made to the state in which one full flux unit is trapped. When the cylinder is cooled in values of field larger than that necessary to produce one unit, the excess flux over one unit is expelled.

It continues to trap one unit until an applied field producing approximately one and one-half flux units within the cylinder is reacher, at which field a sudden transition to two quanta trapped is made. This pattern repeats as a function of field, and for a very thin-walled cylinder produces a sawtooth-shaped magnetization curve. For a thick-walled cylinder the curve has an average slope corresponding to the Meissner effect of the walls, which is proportional to $H_{\text{applied}} \times (\text{wall area})$.

The exact shape of the magnetization curves obtained in these measurements is probably influenced by nonuniformities in the size of the cylinder and in variations of thermal response along the length of the cylinder.

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SPIN-DENSITY-WAVE ANTIFERROMAGNETISM IN POTASSIUM

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It is shown that the recently discussed[1] optical-absorption threshold in metallic K, found by El Naby[2] at $\hbar\omega = 0.62$ eV, provides striking evidence that the electronic state of the metal is a giant spin-density-wave state. The optical absorption associated with the spin-density-wave energy gap is calculated and found to be in remarkable quantitative agreement with the observed spectrum. Direct observation of the spin-density wave by neutron diffraction is feasible, since its amplitude is estimated to be 0.09 Bohr magneton per atom.

In the Hartree-Fock (HF) approximation the normal state of every metal is unstable with respect to spin-density-wave (SDW) formation.[3] However, without an exact solution of the many-body problem, the presence of an SDW can be surmised only from experimental evidence,