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EXPERIMENTAL INVESTIGATION OF THE SURFACE SUPERCONDUCTIVITY OF NIOBIUM

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According to [1], surface superconductivity is possessed by superconductors with a Ginzburg-Landau parameter $0.42 < \kappa < \infty$, including superconductors of the second kind ($1/\sqrt{2} < \kappa < \infty$).

We consider a long cylinder of radius $R \gg \xi$ placed in a longitudinal magnetic field $H_{c2} < H_0 < H_{c3}$. The surface layer of the cylinders forms a superconducting tube surrounding non-superconducting metal. When the magnetic field varies, a current is induced in the tube and screens the inner part of the cylinder.

According to [2], the current reaches a critical value when its magnetic energy becomes equal to the configuration energy enclosed in the superconducting surface layer.

The dependence of the critical value of the current J_c and of the associated magnetization $\pm 4\pi M_c$ of the cylinder on an external magnetic field parallel to the surface is of the form

$$4\pi M_c = \frac{4\pi J_c}{c} = \pm \eta \frac{H_c}{\kappa} \left(\frac{2\lambda}{R}\right)^{1/2} \frac{\Delta}{\xi} F^2(R),$$

where η is a factor on the order of unity, H_c the thermodynamic magnetic field, λ the depth of penetration, R the cylinder radius, Δ the layer thickness, and $F(R)$ the modulus of the wave function on the cylinder surface.

The quantity $(\Delta/\kappa\xi)F^2(R)$ as a function of H_0/H_{c2} is tablulated in [2]. A theoretical calculation of the critical state of the surface layer of the cylinder is also given in [3].

It is seen from the formula that greatest interest attaches to an experimental investigation of superconductors with $\kappa \sim 1$. The only element that is a superconductor of the second kind with $\kappa = 1.1$ at 4.2°K is niobium. The magnetic properties of niobium in the field range $0 < H_0 < H_{c2}$ were investigated in detail in [4], but no verification was made of the concept of the critical state of a superconducting surface layer of niobium samples.

We have investigated cylindrical niobium samples of 0.4 mm diameter and 15 mm length subjected first to thermal etching in oil-free vacuum of 10^{-7} Torr at a temperature close to melting. Control measurements of the sample quality, made in the range $0 < H_0 < H_{c2}$ by a ballistic method, have demonstrated the absence of quenched magnetic moments. The values of H_{c1} and H_{c2} agree with the data of [4].

The procedure for measuring the magnetization of the samples in the $H_{c2} < H_0 < H_{c3}$ region consisted of the following: The samples were placed in a longitudinal magnetic field swept at a rate of 40 Oe/min. An axial alternating magnetic field of 120 Hz frequency was simultaneously applied to the sample. The critical magnetization corresponding to the given value of H_0 was determined from the appearance inside the sample of an alternating current corresponding to $\sim$ 0.005 Oe. The accuracy of measurement of the absolute magnetization was about 5% in the region $H_0/H_{c2} \sim 1.5$ and not worse than 2% in the region $H_0/H_{c2} < 1.5$. The measurements were made in the range $0.84 < H_0/H_{c2} < 1.7$. The results are shown in Fig. 1, from which it is seen

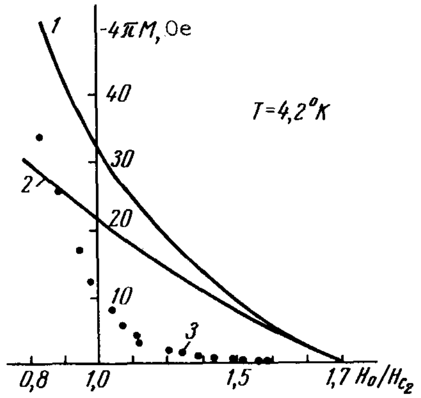

Fig.1. Critical magnetization of niobium superconducting surface layer as calculated by Fink [2] (1) and Park [3] (2) and obtained experimentally (3).

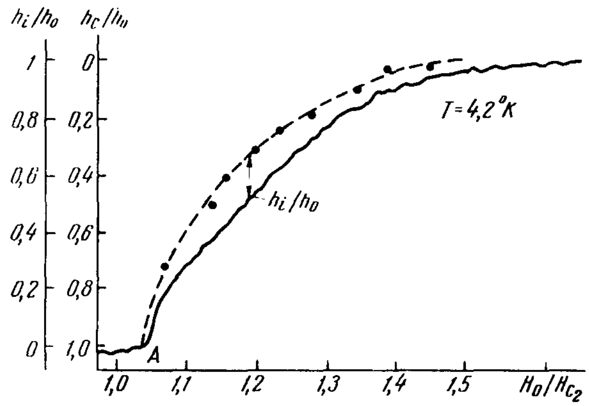

Fig. 2. h_c/h_0 vs. H_0/H_{c2}. The dashed curve corresponds to the lossless case. The arrows indicate the maximum distance between curves, corresponding to maximum hysteresis loss. Modulation amplitude 8.6 Oe.

that when H_0 changes by less than a factor of two, $4\pi M$ changes by three orders of magnitude (0.016 and 34 Oe for $H_0/H_{c2} = 1.48$ and 0.84 respectively). Within the limits of the measurement errors, $H_{c3} = 1.7H_{c2}$ for the investigated samples (see Fig. 2).

The discrepancy between experiment and theory may be due to two causes.

1. Microscopic roughness on the surface, where the surface superconductivity may become destroyed at fields smaller than H_{c3}. Then the effective area of the surface layer remaining in the superconducting state decreases as $H \to H_{c3}$.

2. Approximate character of the theories [2,3].

The presence of an internal alternating field produces in the sample losses connected with reversal of magnetization of the surface layer [5].

Figure 2 shows a direct plot of h_i/h_0 vs. H_0/H_{c2}. The point A corresponds to $h_i = 0$ and $h_c = h_0 = 4\pi M_c$. The dashed curve is drawn through points analogous to A at different h_0 and H_0/H_{c2}, and corresponds to the lossless case. It is seen that the maximum loss (marked by the arrows) is observed at $h_c/h_0 = 0.38 \pm 0.01$, which agrees well with the value $h_c/h_0 = 0.385$, which was predicted theoretically in [5].

An alternating magnetic field induces inside a normal-state sample eddy currents that produce a diamagnetic moment h*. In our experiments h* did not exceed 1% of h_i, and the skin depth in the normal state at ν = 120 Hz greatly exceeded the diameter of the sample. Suitable calculations have shown that the eddy-current loss is small compared with the hysteresis loss.

Comparison of the theoretical and experimental curves (see Fig. 1) has shown the following:

a) In the region $H_0/H_{c2} \sim 1$ the experimental plot of $-4\pi M_c(H_0/H_{c2})$ agrees qualitatively with the theory [2].

b) When $H_0 \to H_{c3}$ the experimental data deviate markedly from those predicted by the theory [2,3].

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FEASIBILITY OF GENERATING AND RECEIVING COHERENT GRAVITATIONAL WAVES BY OPTICALLY "CLOSED" SYSTEMS

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We discuss the possibility of creating a superradiating gravitational state (SGS) of quantum systems [2] that are in a super-nonradiating electromagnetic state (NES) [2]. The latter denotes that the quantum emits under certain conditions photons at a power lower than the power of spontaneous emission of an isolated particle.

The ratio of gravitational and electromagnetic power ($I^{(g)}$ and $I^{(e)}$) radiated by free particles in free space in interatomic and internuclear transitions are respectively $\eta = I^{(g)}/I^{(e)} \sim 10^{-42}$ and 10^{-36}. It was shown in [2] that the use of lasers increases η by a factor $N_c\lambda^3Q$ as a result of a decrease in the spontaneous electromagnetic radiation in the resonator, and by a factor $\tau_p\tau^{-1}N$ as a result of retaining the photons in the resonator (N_c - number of resonator modes, Q - resonator figure of merit, λ - photon wavelength, τ_p and τ - photon lifetime in resonator and duration of particle phosphorescence in free space, respectively, and N - number of particles). As a result the total increase in η may be by 10^{15} - 10^{20} times. In addition, $I^{(g)}$ increases by $\sim N$ times as a result of the coherence of the gravitational waves.

Further increase of η can be obtained by using the directional property of radiation from large systems. The intensity of the coherent part of the spontaneous emission of such systems is (ξ = e or g)

$$I^{(\xi)} \sim \int I_0^{(\xi)}(\mathbf{k}) \sum_{p\neq q} \{ \exp | i[(\mathbf{k} - \sum_{\zeta,\theta} a_{\zeta\theta}\mathbf{k}_{\zeta\theta})\mathbf{r}_p] | \exp | -i[(\mathbf{k} - \sum_{\zeta,\theta} a_{\zeta\theta}\mathbf{k}_{\zeta\theta})\mathbf{r}_q] | \} d\Omega, \quad (1)$$