Contactless method of observing superconductivity in inhomogeneous media

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A sensitive method of searching for high-temperature superconductivity is described briefly. The method makes it possible to detect superconductivity in microscopic regions with characteristic dimensions up to 10^{-4} cm in samples of volume ~ 1 cm^3 prepared in accordance with a special computer program that ensures a broad spectrum of physical properties in individual sections of the specimen.

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The method is based on the known fundamental property of superconductors to "freeze in" the magnetic flux in a cavity that passes through the superconductor. To measure the frozen-in magnetic field it is proposed to observe the rotation of a sample mounted on a sufficiently thin suspension when the sign of the homogeneous magnetic field is reversed. Under these conditions, the torque depends only on the value of the frozen-in flux and does not depend on the magnetic susceptibility or on the mass of the specimen.

Denoting the strength of the superconducting current around the cavity by J, we obtain the torque M in the field H

$$M = \int J H r \, dl \, ,$$

where r is the characteristic dimension of the cavity and dl is the element of length. Assuming that the magnetic field remains unchanged in the transition to the superconducting state, we get

$$M \approx H^2 r^3 \tag{1}$$

accurate to a coefficient on the order of unity. In (1) the minimal value of r is determined by the torque M_0 acting on the sample as a result of the finite magnitude of the inhomogeneity of the magnetic field, of the sample, and of the asymmetry of the sample relative to the rotation axis. This torque is equal to

$$M_0 = \int_V \chi(x, y, z) H R \cdot \nabla H \, dm \, , \tag{2}$$

where χ is the local magnetic susceptibility of the mass dm, R is the distance of dm from the rotation axis, ∇H is the gradient of the magnetic field, and V is the volume of the sample in which the integration is carried out. From (2) it follows that in a strictly homogeneous magnetic field in the torque is equal to zero. By passing a vertical plane through the sample rotation axis and the magnetic field H, we obtain from (1) and (2), provided that ∇H is small and is the same over the entire volume of the sample,

$$\frac{M_0}{M} \approx \frac{\overline{\chi m R} \, \nabla H}{H r^3} \, ,$$

where $\overline{\chi m R} = \int_1 \chi R\, dm - \int_2 \chi R\, dm$ and the integrals are taken over the right and left sides relative to the plane. Thus, $M_0 \neq 0$ only for asymmetrical samples. Assuming for example that one of the sides of the sample contains a defect—a void of radius a, we get

$$\frac{M_o}{M} \approx \frac{4\pi\rho a^3 \chi R \nabla H}{3Hr^3},$$

where ρ is the density of the sample. By way of estimate we put $a = 0.05$ cm, $\rho = 1$, $R = 0.5$ cm, $\chi = 10^{-5}$ and $\nabla H/H = 10^{-4}$ and obtain $M_0/M \approx 10^{-12} r^{-3}$, while at $M_0 = M$ we obtain $r \approx 10^{-4}$ cm. This estimate shows that even a relatively large inhomogeneity of the sample has an insignificant effect on the sensitivity of the method. We note that even an ideally symmetrical sample will be displaced at $\nabla H \neq 0$ into the region of the stronger or weaker magnetic field, depending on the sign of the magnetic susceptibility. This displacement, however, is negligible.

Since the torsion method is in general very sensitive to ferromagnetic contaminations of the sample, these should be avoided.

In the ideal case, the data fed to the computer in order to assemble the selected substances should lead to the construction of such a model of the structure, in which any changes of parameters (say the temperature, pressure, dissolution, etc.) give perfectly known combinations of substances in any cell $V_0 \approx r^3$ of the sample. In practice we do not always know the properties of the initial materials and of their combinations, so that in the actual experiment there will be regions whose composition and parameters have not been determined. However, no matter how large the percentage of this region, the problem of finding the conditions for the formation of the superconducting sections can be solved in a relatively small number of experiments. For example: 1) by varying the principal parameters one reaches the maximum effect; 2) reproducibility of the results is established; 3) by eliminating one or several substances one determines those causing the superconductivity; 4) the computer is used to change over to experiments with ever increasing structure elements, and finally, to prepare a sample with a single structure.

It is interesting to note that complete identification of the conditions under which superconductivity is produced is not always necessary, since the experiment makes it possible to determine directly such important parameters as the critical temperature and the critical magnetic fields. Therefore, if it turns out that these parameters do not correspond to the requirements of the technology, the investigation can be discontinued.

All these questions will be discussed in greater detail in a forthcoming paper.