NUCLEAR MAGNETIC RESONANCE IN THE RESISTIVE STATE OF SUPERCONDUCTORS OF THE SECOND KIND

I. O. Kulik
Physico-technical Institute of Low Temperatures, Ukrainian Academy of Sciences
Submitted 2 June 1966
ZhETF Pis'ma 4, No. 4, 138-140, 15 August 1966

As shown earlier [1,2], the motion of magnetic flux filaments in superconductors of the second kind in the "resistive" state ($H_{c1} < H < H_{c2}$, $j_\perp > j_{cr}$) leads to the occurrence of high-frequency radiation, which is monochromatic if the filaments form a regular lattice and move with constant velocity (such a situation can be realized in fully homogenized superconducting alloys). In the present paper we propose a method for observing this phenomenon with the aid of nuclear magnetic resonance (NMR). Unlike superconductors of the first kind, in this case the magnetic field penetrates into the volume of the metal, so that there is no need for using very small samples. The most suitable region for the investigation of NMR is the region near H_{c2} [3], where the field fluctuations inside the superconductor are small, thus causing the existence of sufficiently narrow lines.

The calculation of the proposed effect, based on the use of the Bloch equations [4], leads to the following expression for the radiation power absorbed by the spin system (H near H_{c2}):

$$\bar{A}(\omega) = \omega\omega_0\chi H_1^2 \sum_{n=-\infty}^{\infty} I_n^2(\gamma h/\Omega)\,\frac{1}{a}\int_0^a dx\,\frac{1/T_2}{(\omega - \omega_0 - n\Omega + \gamma h\cos(2\pi x/a))^2 + 1/T_2^2}\,. \quad (1)$$

Here a is Abrikosov's structure period [3], $\Omega = (2\pi c/s)(E/H)$ the frequency of the radiation produced when the filaments move [1,2], $\omega_0 = \gamma\bar{H}$ the NMR frequency, T_1 and T_2 the nuclear relaxation times, and h the amplitude of the alternating part of the magnetic field in the superconductors ($h \sim M \sim H_{c2} - H$). Formula (1) is valid in the absence of saturation, when $\Omega T_1 \gg 1$ and the Knight shift is neglected.

As seen from (1), the following singularities are produced in the NMR spectrum when the vortices move:

1. Besides the main resonance at $\omega = \omega_0$, "satellites" appear, with frquencies $\omega_n = \omega_0 + n\Omega$. Their intensity is determined by the same expression as the main resonance at an exciting-field amplitude, $H_1^* = H_1|I_n(\gamma h/\Omega)|$ (with $\gamma h \ll 1/T_2$). Under saturation conditions, the intensity of the NMR signal does not depend on H_1 and its value for the n-th satellite is

$$\bar{A}_n^{max} = (\omega_n\omega_0\chi)/\gamma^2 T_1, \quad \gamma^2 = (H_1^*)^2 T_1 T_2 \gtrsim 1 \quad (2)$$

(the second relation determines the values of H_1 required to reach saturation).

2. The NMR line differs greatly in shape from Lorentzian if $\gamma h \gtrsim 1/T_2$. When the vortex structure moves, the absorption line becomes narrower and changes in shape.

More detailed calculations will be published later. The purpose of the present note was to call attention to NMR as an effective tool for the study of the structure and distribution of the internal fields in superconductors of the second kind.

In conclusion I am grateful to M. I. Kaganov for discussions.

[1] I. O. Kulik, JETP Letters 3, 183 (1966), transl. p. 116.
[2] I. O. Kulik, JETP 50, 1617 (1966), Soviet Phys. JETP 23, in press.
[3] A. A. Abrikosov, JETP 32, 1442 (1957), Soviet Phys. JETP 5, 1174 (1957).
[4] A. Loesche, Nuclear Induction, Chapter 2, IIL, 1963.

DISTRIBUTION FUNCTION OF DISTANCES BETWEEN ENERGY LEVELS OF AN ELECTRON IN A ONE-DIMENSIONAL RANDOM CHAIN

V. L. Pokrovskii
Institute of Theoretical Physics, USSR Academy of Sciences
Submitted 4 June 1966
ZhETF Pis'ma 4, No. 4, 140-144, 15 August 1966

The distribution of level spacing in systems that are in some sense random has recently again attracted persistent interest on the part of the theoreticians. Physical examples of such systems are atomic nuclei in strongly excited states [1,2], and small metallic particles [3,4].

Random systems are presently described phenomenologically. Dyson [2] has proposed that level spacing can be described by one of three possible ensembles (unitary, symplectic, orthogonal), depending on the symmetry properties of the system. A similar initial hypothesis is used by Gor'kov and Eliashberg [4]. It is assumed in this case that these ensembles correspond to maximally randomized systems. It is very attractive to attempt to find, starting from the general principles of dynamics and probability theory, arguments in favor of Dyson's distributions, of at least the same type as already exist for the Gibbs distribution. In addition, it would be interesting to ascertain which ensembles describe level distribution for incompletely random systems.

In this paper we investigate the simplest one-dimensional model for which it is possible to obtain an explicit solution of the problem of the distribution of distances between energy levels. The obtained distribution has no similarity whatever to the Dyson distribution [2]. The character of the distribution (very narrow Gaussian peaks) is apparently connected in its essential features with the assumed simplifications of the model (one-dimensionality, absence of interactions between "electrons"). Since, however, this is the only known example where the problem is solved exactly, its results are also of interest in themselves.

Let us consider a one-dimensional chain of potential centers between which a quantum particle (electron) moves. For simplicity let us assume that the effective radius of the center is much smaller than the average distance between centers. In the zeroth approxima-