Solid State Communications, Vol.53,No.11, pp.961-966, 1985.
Printed in Great Britain.

0038-1098/85 $3.00 + .00
Pergamon Press Ltd.

"EXCHANGE-FIELD-NARROWING" PROCESS FOR THE INHOMOGENEOUSLY BROADENED EPR LINES IN SUPERCONDUCTORS

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(Received 14 December 1984 by E.A.Kaner)

A simplified version of the theory, describing the narrowing of inhomogeneously and dipolar broadened EPR lines by the long range exchange in superconductors, is presented. This is the so-called "exchange-field-narrowing"process, in which the localized magnetic moments precessing with different frequencies are coupled by the exchange molecular fields, but not by the mutual spin flips. It is also shown that a simple formula for the width of exchange narrowed EPR line can be obtained which takes into account the effects of both the exchange fields and the exchange fluctuations.

1. Introduction

It is well known (see e.g.[1,2]) that the NMR line broadens just below the superconducting transition temperature T_c. This broadening is explained by the increase of Korringa relaxation rate of nuclear moments to the conduction electrons due to increasing of electronic density of states near the superconducting gap edge and the coherence effects. According to the generally accepted point of view (see [3]), the electronic localized moment (LM) in a superconductor should relax in the same way as the nuclear moment, hence the qualitative temperature dependence of the linewidth should be the same as in NMR. But in EPR measurements on the LMs of Er^{3+} in superconducting La (cubic β-phase) a sharp decrease of linewidth has been observed upon going into the superconducting state[4]. It can not be explained by the switching off of the Korringa relaxation due to the narrowing of the "electronic bottleneck" (see e.g.[5]), because the magnitude of narrowing considerably exceeds the contribution of the Korringa relaxation mechanism to the linewidth. Note the presence of large residual width (obtained by extrapolation to zero temperature of linear temperature dependence of the linewidth) and dependence of the degree of narrowing on concentration of Er ions[4]. This shows that two-particle spin-spin interactions play an essential role in the narrowing process.

It was shown in [4,6] that in superconducting state the indirect exchange interaction of LMs via conduction electrons markedly changes and it can be represented by two terms. The first term is an ordinary RKKY interaction

$$H^{RKKY}_{ex} = \sum_{i>j} J^{RKKY}_{ij} (\vec{S}_i \cdot \vec{S}_j) , \qquad (1)$$

$$J^{RKKY}_{ij} = \frac{4\pi J^2_{sf} \rho^2_F \varepsilon_F}{(2k_F)^3} \frac{\cos 2k_F r_{ij}}{r^3_{ij}} e^{-\frac{r_{ij}}{l_p}} ,$$

the second one is the long range interaction of antiferromagnetic sign, which appears only in the superconducting phase

$$H^S_{ex} = \sum_{i>j} J^S_{ij} (\vec{S}_i \cdot \vec{S}_j) , \qquad (2)$$

$$J^S_{ij} = \frac{1}{r_{ij}} \frac{3}{2} \left(\frac{\pi \rho_F J_{sf}}{k_F} \right)^2 T \sum_{\omega_n} \frac{1}{1+u^2} \frac{\gamma}{l_p}$$

$$\times \exp\left\{ - \frac{r_{ij}}{l_p} \left[\frac{\Delta\sqrt{1+u^2}}{\varepsilon_F} k_F l_p - \frac{2 l_p}{3 l_s} \frac{2u^2+1}{u^2+1} + \frac{4 l_p}{3 l_{so}} \right]^{1/2} (3\gamma)^{1/2} \right\} ,$$

$$\gamma = 1 - \frac{l_p}{l_s} + \frac{\Delta\sqrt{1+u^2}}{\varepsilon_F} k_F l_p + \frac{l_p}{l_{so}} ,$$

$$r_{ij} = |\vec{r}_i - \vec{r}_j| .$$