Phenomenological derivation of nonmonotonic temperature dependences in antiferromagnetic superconductors using a two-fluid model

G. Dharmadurai
Reactor Research Centre, Kalpakkam-603 102, Tamil Nadu, India
(Received 17 April 1981)

We demonstrate that the nonmonotonic temperature dependences of the upper critical field and the superconducting order parameter of an antiferromagnetic superconductor can be deduced phenomenologically from a modified version of the well-known two-fluid model.

In a recent letter, Nass *et al.*[1] have obtained a nonmonotonic temperature (T) dependence for the thermodynamical critical field [$H_c(T)$] and gap parameter $\Delta(T)$ of an antiferromagnetic superconductor,[2] using a rigorous mean-field theory which assumes phonon-mediated pairing in the system. Without prejudice to possible interplay of nonphononic mechanisms,[3] which might either favor or counteract superconductivity in this complex system, we suggest that it may be possible to deduce a nonmonotonic temperature dependence phenomenologically as exemplified below by considering a modified version of the well-known two-fluid model.[4]

In zero magnetic field, we can relate the superfluid concentration $X_0(T)$ of an ordinary superconductor to its thermodynamic critical field $H_{c0}(T)$ through,[4]

$$H_{c0}^2(T) = H_0^2[2(T^2/T_c^2)[1-X_0(T)]^{1/2} + X_0(T) - 2T^2/T_c^2] \ , \tag{1}$$

where $X_0(T) = 1 - T^4/T_c^4$ and H_0 is the critical field at zero temperature. For an antiferromagnetic superconductor which manifests a molecular field[1,2] $H_Q(T)$ below the Néel temperature T_N, we assume that the modified superfluid concentration $X(T)$ can be approximately described by

$$X(T) = X_0(T)F(H_Q/H_{c2}) \ , \tag{2}$$

with the function $F(H_Q/H_{c2})$ chosen such that $F(0)=1$ and $F(1)=0$. Here, $H_{c2}(T) = \sqrt{2}K(T)H_c(T)$ is the upper critical field[1,2] of the anitferromagnetic superconductor and the parameter $K(T)$ in the two-fluid model can be approximated[5] by

$$K(T) = K(0)(1+T^2/T_c^2)^{-1/2}(1+T/T_c)^{-1/2} \ .$$

Following Nass *et al.*,[1] we assume $T_N = T_c/2$, but with an alternative description $H_Q(T) = H_Q(0) \times (1-T^2/T_N^2)^{1/2}$. Further we choose $F(H_Q/H_{c2}) = (1-H_Q/H_{c2})^2$ as a trial function. Under these modifications, the thermodynamical critical field $H_c(T)$ of the antiferromagnetic superconductor will follow from Eq. (1) if we replace $X_0(T)$ by the modified value $X(T)$.

In terms of the reduced variables, $t = T/T_c$, $h(t) = H_c(T)/H_0$ and $h_q(0) = H_Q(0)/[\sqrt{2}K(0)H_0]$, the expression for the critical field of an antiferromagnetic superconductor would become

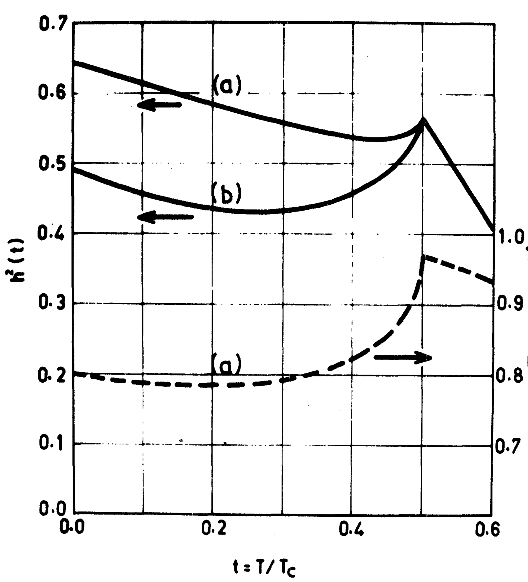

FIG. 1. Temperature dependence of $h(t)$ and $X(t)/X_0(0)$ of an antiferromagnetic superconductor for $h_q(0)=0.16$ (curves a) and 0.21 (curve b).

$$h^2(t) = (1-t^4)\left[1 - \frac{h_q(0)}{h(t)}(1+t^2)^{1/2}(1+t)^{1/2}(1-4t^2)^{1/2}\right]^2$$
$$+2t^2\left[1-(1-t^4)\left[1-\frac{h_q(0)}{h(t)}(1+t^2)^{1/2}(1+t)^{1/2}(1-4t^2)^{1/2}\right]^2\right]^{1/2} - 2t^2 \ . \quad (3)$$

For $T \geqslant T_N$, $H_Q(T) = 0$ and the above equation will simply reduce to the familiar parabolic form.[4]

In Fig. 1, we depict the variation of $h^2(t)$ with t for $h_q(0) = 0.16$ and 0.21 as obtained from Eq. (3) and also the temperature dependence of $[X(t)/X_0(0)]^{1/2}$ as obtained from Eq. (2) for $h_q(0) = 0.16$. We find that in spite of the crudeness of the various approximations used, the nonmonotonic temperature dependence[1,2] of the thermodynamical critical field and of the superfluid order parameter is also qualitatively borne out by this simple two-fluid picture, irrespective of the pairing and depairing mechanisms that might be operative in an antiferromagnetic superconductor.

ACKNOWLEDGMENT

The author is very grateful to Dr. H. N. Sethna, Chairman of the Indian Atomic Energy Commission, for encouragement.

[1]M. J. Nass, K. Levin, and G. S. Grest, Phys. Rev. Lett. 46, 614 (1981).

[2]K. Machida, K. Nakora, and T. Matsubara, Phys. Rev. B 22, 2307 (1980); Phys. Rev. Lett. 44, 821 (1980), and references therein.

[3]M. Peter, J. Ashkenazi, and M. Dacorogna, J. Phys. (Paris) 39, C6-1404 (1978); S. N. Ekbote and A. V. Narlikar, Mater. Res. Bull. 15, 827 (1980); Solid State Commun. 38, 1007 (1981), and reference therein.

[4]E. A. Lynton, *Superconductivity* (Chapman and Hall, London, 1974), p. 20.

[5]G. D. Cody, in *Superconducting Magnet Systems*, edited by H. Brechna (Springer-Verlag, Berlin, 1973), p. 166.