

The lower critical field in high-T_C superconductors

Autor(en): **Nicula, Al. / Crian, M.**

Objektyp: **Article**

Zeitschrift: **Helvetica Physica Acta**

Band (Jahr): **61 (1988)**

Heft 4

PDF erstellt am: **11.09.2024**

Persistenter Link: <https://doi.org/10.5169/seals-115948>

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.

Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.

Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

The lower critical field in high- T_c superconductors

By Al. Nicula and M. Crişan

Department of Physics, University of Cluj-Napoca, 3400 Cluj-Napoca, Romania

(26. XI. 1987)

In honor of Martin Peter's 60th birthday.

Abstract. Using a two-dimensional Fermi surface model for a high temperature superconductor we calculated the temperature dependence of the lower critical field H_{c1} . The new temperature dependence in H_{c1} is given by the temperature dependence of the London penetration depth $\lambda(T)$, but an additional contribution appears and this is contained in the number of superconducting electrons n_s and the gap which are also temperature dependent.

1. Introduction

The high-temperature superconductivity recently discovered by Berdnorz and Müller [1] in the La-Ba-Cu-O system has enjoyed an immense experimental [2] and theoretical interest [3–5] in the last period. The important problem which has been intensively studied by Chu et al. [6], Wu et al. [7] and Cava et al. [8] was to obtain a great number of materials which present superconductivity at high temperature. In order to predict the critical temperature and to propose a mechanism for the explanation of the superconductivity at high temperatures Jalborg, Junod and Peter [9] accurately calculated the critical temperature of the A15 compounds on the basis of the band structures.

In these new compounds the role of the electrons of O and of Cu (which seems to have the valence only approximatively fixed as Cu^{+2} (d^9)) have to be taken into consideration together.

Recently the systematic band calculations [10] showed that systems $\text{La}_{2-x}(\text{Sr}, \text{Ba}, \text{Ca})_x\text{CuO}_4$ present a two dimensional Fermi surface with an imperfect nesting on the direction of the wave function $\vec{Q} = [\pi, \pi]$. Using these results Machida and Kato [11] considered a two dimensional model for the Fermi surface and calculated the critical temperature for a high temperature superconductor.

The purpose of this paper is to calculate the temperature dependence of the lower critical field H_{c1} a high temperature superconductor with two dimensional Fermi surface.

2. The Model

In order to calculate the lower critical field H_{c1} we start with the following mean field Hamiltonian

$$H = H_0 + H_{SC} + H_{SDW} \quad (1)$$

where

$$H_0 = \sum_{\vec{u}, \alpha} \varepsilon(\vec{k}) C_{\vec{u}\alpha}^+ C_{\vec{u}\alpha} \quad (2)$$

$$H_{SC} = - \sum_{\vec{u}, \alpha} (\Delta(\vec{u}) C_{\vec{k}\alpha}^+ C_{-\vec{k}, -\alpha}^+ + \text{h.c.}) \quad (3)$$

$$H_{SDW} = - \sum_{\vec{k}} M (C_{\vec{k}+\vec{Q}\uparrow}^+ C_{\vec{u}\downarrow} + \text{h.c.}) \quad (4)$$

The first term is the kinetic energy of two dimensional square lattice (the lattice constant $a = 1$), namely

$$\varepsilon(k) = -t(\cos k_x + \cos k_y) \quad (5)$$

where t is the nearest neighbour transfer integral. We assume that the band is half-filled to ensure the Spin-Density-Waves (SDW) nesting with the wave vector \vec{Q} . The SDW order parameter M is defined self-consistently by

$$M = U \sum_{\vec{k}, \omega} \langle C_{\vec{k}+\vec{Q}\uparrow}^+ C_{\vec{u}\downarrow} \rangle \quad (6)$$

where U is the repulsive Coulomb interaction. We will consider the d -pairing state (which is compatible with the square symmetry and in this case the superconducting order parameter is

$$\Delta_d(\vec{k}) = \sum_{\vec{k}', \alpha} g_d(\vec{u}, \vec{k}') \langle C_{\vec{k}', \alpha} C_{-\vec{k}', -\alpha} \rangle \quad (7)$$

where

$$\Delta_d(\vec{k}) = \Delta \tau_d(\vec{k}) = \frac{\Delta}{2} (\cos k_x - \cos k_y)$$

and the coupling constant

$$g_\alpha(\vec{u}, \vec{u}') = g \tau_\alpha(\vec{u}) \tau_d(\vec{k}')$$

The equations for M and Δ have been obtained by Kato and Machida [11] as

$$1 = \frac{U}{\pi t} T \sum_{\omega} \frac{1}{\sqrt{\omega^2 + \Delta^2 + M^2}} \ln \frac{2\pi t}{\sqrt{\omega^2 + M^2}} \quad (8)$$

$$1 = \frac{g}{\pi t} T \sum_{\omega} \left\{ \frac{1}{\sqrt{\omega^2 + \Delta^2 + M^2}} \ln \frac{2\pi t}{\sqrt{\omega^2 + \Delta^2}} - \frac{1}{2\Delta} \ln \left| \frac{\sqrt{\omega^2 + \Delta^2 + M^2} + \Delta}{\sqrt{\omega^2 + \Delta^2 + M^2} - \Delta} \right| \right\} \quad (9)$$

These equations can be solved and one obtains three domains

- (a) the superconducting domain $\Delta \neq 0, M = 0$
- (b) the coexistence domain $\Delta \neq 0, M \neq 0$
- (c) the magnetic domain $\Delta = 0, M \neq 0$.

In the following we concern ourselves with the superconducting domain and in this case the equation (9) becomes

$$1 = \frac{g}{\pi t} T \sum_{\omega} \left\{ \frac{1}{\sqrt{\omega^2 + \Delta^2}} \ln \frac{2\pi t}{|\omega|} - \frac{1}{2\Delta} \ln \left| \frac{\Delta + \sqrt{\omega^2 + \Delta^2}}{\Delta - \sqrt{\omega^2 + \Delta^2}} \right| \right\} \quad (10)$$

3. The Lower Critical Field

The lower critical field H_{c1} is expressed [12] by the energy of a single vortex E_v as

$$H_{c1} = 2|e|E_v \quad (11)$$

where E_v is given by the general expression [13]

$$E_v = 2\pi \int_0^{\infty} r d\pi \int_0^g d\left(\frac{1}{g}\right) [|\Delta(r)|^2 - |\Delta(o)|^2] \quad (12)$$

where $\Delta(r)$ is the superconducting order parameter in the presence of the magnetic field, and $\Delta(o)$ the order parameter for a homogeneous superconductor. The order parameter $\Delta(\vec{r})$ will be expanded as

$$\Delta(\vec{r}) = \Delta(o) + \Delta_1(\vec{r}) + \dots \quad (13)$$

where $\Delta_1(\vec{r})$ is the first order correction due to the presence of the magnetic field. Using now the equation (10) we can calculate $d(1/g)$ and (12) becomes

$$E_v = 2\pi \int_0^{\infty} r d\pi \int_0^{\infty} C(\Delta) \Delta_1(r) \frac{d\Delta}{\Delta} \quad (14)$$

where $C(\Delta)$ is

$$C(\Delta) = -\frac{1}{\pi t} \left[2\pi T \sum_{\omega}^{\omega_v} \left(\frac{\Delta^2}{E^3} \ln \frac{\pi t}{\omega} - \frac{1}{2\Delta} \ln \left| \frac{\Delta + E}{\Delta - E} \right| + \frac{1}{E} \right) \right] \quad (15)$$

where $E^2 = \omega^2 + \Delta^2$, $\omega = \pi T(m + \frac{1}{2})$. The first order correction $\Delta_1(r)$ has been calculated [13] as

$$\Delta_1(r) = -\frac{(ev_0 A(r))^2}{3} \left[\sum_{\omega} \frac{1}{\eta E^3} \right] \left[\sum_{\omega} \frac{1}{E^3} \right]^{-1} \quad (16)$$

where

$$\eta = 1 + \frac{1}{\tau_r E}$$

being the transport scattering time and $\vec{A}(\vec{r})$ the potential vector for a vortex. In the following we will take $\vec{A}(\vec{r})$ as [13]

$$A(r) = \frac{1}{2|e|r} K_1\left(\frac{r}{\lambda}\right) \quad (17)$$

where $K_1(x)$ is the Bessel function of the imaginary argument. For a London superconductor the integral over 'r' in the equation (14) gives the main contribution for $\lambda < r < \xi$ (ξ is the London penetration depth and λ the coherence length) and $\vec{A}(\vec{r})$ can be approximated as

$$A(r) \cong \frac{1}{2|e|r} \quad (18)$$

With these results we get from (11), (15) and (16) the critical field H_{c1} as

$$H_{c1} = \frac{\Phi}{4\pi\lambda^2} \left[\frac{1}{mt} \left(\ln \frac{\pi t}{\omega_D} + \frac{n}{n_s(T)} \ln \Delta(T) \right) - \frac{n}{n_s(T)} 2T \frac{\ln \cosh \Delta(T)/2T}{\Delta(T) \tanh \Delta(T)/2T} \right] \ln \frac{\lambda}{\xi} \quad (19)$$

where ω_D is the Debye frequency and $n_s(T)$ is the number of electrons in the superconducting state. For a BCS superconductor H_{c1} has been calculated [12–13] as

$$H_{c1} = \frac{\Phi}{4\pi\lambda^2} \ln \frac{\lambda}{\xi} \quad (20)$$

and from (19, 20) we see that in the two dimensional superconductor, as it is supposed to be a high temperature superconductor, we expect an important enhancement in the temperature dependence of the lower critical field.

REFERENCES

- [1] J. BEDNORZ and K. A. MÜLER, *Z. Phys.* B64, 189 (1986).
- [2] See papers collected in the special issue: *Jpn. J. Appl. Phys.* 26 No. 4, pt. 2 (1987).
- [3] L. F. MATTHEISS, *Phys. Rev. Lett.* 58, 1028 (1987).
- [4] J. YU, A. J. FREEMAN and J. H. XU, *Phys. Rev. Lett.* 58, 1035 (1987).
- [5] P. W. ANDERSON *Science* 235, 1196 (1987).
- [6] C. W. CHU, P. H. HOR, R. L. MENG, L. GAO, Z. J. HUANG and Y. Q. WANG, *Phys. Rev. Lett.* 58, 405 (1987).
- [7] M. K. WU, J. R. ASHBURN, C. J. TORNG, P. H. HOR, R. L. MENG, L. GAO, Z. J. HUANG, Y. Q. WANG and C. W. CHU, *Phys. Rev. Lett.* 58, 908 (1987).
- [8] R. J. CAVA, R. B. VAN DOVER, B. BATLOGG and E. A. RIETMAN, *Phys. Rev. Lett.* 58, 408 (1987).
- [9] T. JALBORG, A. JUNOD and M. PETER, *Phys. Rev. B.* 27, 1558 (1983).
- [10] Y. YAMAGUCHI, H. YAMAUCHI, M. OHASHI, H. YAMAMOTO, N. SHIMODA, M. KIKUCHI and Y. SYOMO, *Jpn. Appl. Phys.* 26, L447 (1987).
- [11] M. KATO, and y. MACHIDA, *J. Phys. Soc. Jpn.* 56, 2136 (1987).
- [12] P. G. DE GENNES, *Superconductivity of Metal and Alloys* (New York, W. A. Benjamin Inc. 1966).
- [13] T. K. MELIK-BARKHUDAROV, *J. Eksp. Teor. Fiz.* 47, 311, 1964 (*Sov. Phys. JETP*-20, 208 (1965)).