

UPPER CRITICAL FIELD H_{c2} IN TWO-BAND SUPERCONDUCTORS

M.E. Palistrant

*Institute of Applied Physics of the Academy of Sciences of Moldova ,
Academiei str. 5 , Kishinev, MD2028 ,The Republic of Moldova*

Abstract

The equation for the definition of upper critical field H_{c2} in the system with two overlapping energetic bands on the Fermi surface, which is valid for the whole temperature interval $0 \leq T < T_c$ was obtained. The analytic expressions for the value H_{c2} at $T \sim T_c$ and $T \ll T_c$ cases were defined. The possibility of changing the curvature $H_{c2}(T)$ with changing of the electron speed ratio v_1/v_2 on different cavities on the Fermi surface was revealed. The qualitative accordance with experimental data for the intermetallic compound MgB_2 was obtained,

Keywords: Superconductivity, two-band model, upper critical field, magnezium borid.

1. Introduction

The discovery of the high temperature of superconductive transition $T_c \sim 40K$ in the simple intermetallic compound MgB_2 [1] has stimulated researches of this material properties both in the experimental and theoretical plans. An overview of the basic physical properties of MgB_2 can be seen, for example, in [2]. The significant result of these researches is the discovery of two energetic gaps in the spectrum of the elementary excitations [3,4] and the possibility of theoretical describing of this compound on the base of the two-band model [5] (see also [6]).

The theory of the thermodynamic and kinematic properties of superconductors (pure and doped) with overlapping energy bands on the Fermi surface was developed by Moskalenko and his collaborators (for the references to the articles see [7]-[9]). The typical feature of two-band model is the fact, that it gives not only the quantitative difference from the one energy band case, but leads to the qualitatively new results [7]. Being built long before the discovery of the superconductivity in MgB_2 , this theory can generally describe the superconductive properties of this compound. Nowadays rediscovering of already known results, which had been obtained in the previously mentioned articles often happens,

Moskalenko two-band model [5] and its generalization for the anisotropic value of the energetic gaps Δ_1 and Δ_2 case [10,11], confirm the experimental results for the thermal capacity C_s dependence on temperature, the penetration depth of the magnetic field λ (T) and other characteristics in the superconducting MgB_2 compound.

As it is known, the superconductive metals undergo the transition from the superconductive phase into normal in the magnetic field at its certain value. Researching the Ginzburg-Landau equation, Abrikosov has shown [12] that at a certain value of the exterior magnetic field H_{c1} (lower critical field) the mixed state realizes in the secondary type superconductors. This state is characterized by penetration of the magnetic field in the deep of superconductor as the exact lattice of the magnetic lines. The transition into the normal state, which is relevant to the full penetration of the magnetic field into the superconductor, occurs at the moment when the field achieves the value of the upper critical field H_{c2} . Definition of this value on the base of the Ginzburg-Landau theory is possible only in the critical

temperature neighbourhood. The H_{c2} value is defined in the whole temperature interval in Gorikov article [13] (see also Maki and Tsuzuki [14]).

In the previously mentioned articles an isotropic superconductor was considered. It is interesting to research the magnetic properties of anisotropic superconductors because real superconductors are so. Overlapping of the energy bands [5] is one of the manifestations of anisotropy. There were obtained base equations of the electrodynamics of two-band superconductors in work [15], which are valid for both pure and doped superconductors. The electromagnetic properties of two-band superconductors for temperatures close to the critical ($T_c - T \ll T_c$) were also researched.

The main purpose of the work is researching of pure two-band superconductor of the secondary type for arbitrary temperatures and external magnetic field close to the upper critical field and the definition of temperature dependence of the H_{c2} value.

2. The system of equations for the order parameters Δ_n .

If the exterior magnetic field is great enough, the order parameters Δ_m ($m=1,2$) of two-band superconductor is small and we can use equations ref. [15] for pure two-band superconductor:

$$\Delta_m^*(\vec{x}) = \frac{1}{\beta} \sum_{\omega} \sum_{nn'} V_{nm} \int d\vec{y} g_{n'n}(\vec{y}, \vec{x} / \omega) \Delta_{n'}^*(\vec{y}) g_{n'n}(\vec{y}, \vec{x} / -\omega) \quad (1)$$

We restricted here by linear terms on Δ_n quantities in comparison with given in [15] because in the $H=H_{c2}$ point solutions with the infinitely small values Δ_m occurs. Green function is defined by equation at presence of the magnetic field [16]:

$$g_{m'n'}(r, r' / \omega) = e^{i\varphi(r, r')} g_{n'n}^0(r, r' / \omega) \quad (2)$$

Where $g_{n'n}^0$ is the Green function of an electron in normal metal without magnetic field. The presence of the magnetic field is taken into account by the phase multiplier

$$\varphi(r, r') = e \int_{r'}^r A(\vec{l}) d\vec{l} \quad (3)$$

We decompose in equation (1) the normal metal function $g_{n'n}^0$ into the row by the Bloch functions $\psi_{n\vec{k}}(\vec{x}) = e^{i(\vec{k}\vec{x})} U_{n\vec{k}}(\vec{x}) / \sqrt{N}$ ($U_{n\vec{k}}$ - the Bloch amplitude):

$$g_{n'n}^0(\vec{y}, \vec{x} / \omega) = \sum_{\vec{k}\vec{k}'} g_{n'n}^0(\vec{k}', \vec{k} / \omega) \psi_{n'\vec{k}'}(\vec{y}) \psi_{n\vec{k}}^*(\vec{x}) \quad (4)$$

and use approaching of the diagonal Green functions, which were developed in works [17]. Besides we choose the vector potential as

$$A_x = A_z = 0 ; \quad A_y = H_0 x \quad (5)$$

(magnetic field is guided along the z axis).

Equation (1) will accept the following form:

$$\begin{aligned} \Delta_m^*(r) = & \sum_n V_{nm} \frac{1}{\beta} \sum_{\omega} \int d^3 r' \Delta_n^*(r') \int \frac{d^3 k d^3 q}{(2\pi)^6} g_n^0(\vec{k}/\omega) \times \\ & \times g_n^0(\vec{q}-\vec{k}/-\omega) \exp[i\vec{q}(\vec{r}'-\vec{r}) + ie(x+x')(y'-y)H_0] U_{n\vec{k}}(\vec{r}') \times \\ & \times U_{n\vec{k}}^*(\vec{r}) U_{n\vec{q}-\vec{k}}(r') U_{n\vec{q}-\vec{k}}^*(r), \end{aligned} \quad (6)$$

$$g_n^0(\vec{k}/\omega) = \frac{1}{i\omega - \xi(k)}. \quad (7)$$

After integrating by impulse k , we make the averaging by elementary cells, in order to exclude from consideration fast oscillations of function Δ_n (which are stipulated by Bloch functions) and to save just dependence on these functions' coordinates (incipient due to the exterior magnetic field presence), because just last dependence is observed. As a result we obtain:

$$\begin{aligned} \Delta_m^*(r) = & \sum_n V_{nm} \frac{1}{\beta} \sum_{\omega} \int d\Omega \int \frac{d^3 q}{(2\pi)^3} \frac{N_n \omega}{2|\omega|} \frac{i}{2i\omega + \vec{q}\vec{v}_n} \times \\ & \times \int d^3 r' \Delta_n^*(r') \exp[iq(r-r') + ieH_0(x+x')(y'-y)], \end{aligned} \quad (8)$$

where v_n and N_n are accordingly electron speed and electron density of state on n -th cavity of the Fermi surface. Applying to the calculation of equation's (8) left part Maki and Tsuzuki methodic [14], and supposing that Δ_n depends just on x^1 , we obtain on this way:

$$\begin{aligned} \Delta_m^*(x) = & \sum_n \frac{V_{nm} \pi N_n}{\beta v_n} \int_1^{\infty} \frac{du}{u} \int_{-\infty}^{\infty} dx' \Delta_n^*(x') \times \\ & \times \frac{J_0\left[\frac{(x^2-x'^2)eH_0\sqrt{u^2-1}}{2|x-x'|\pi u}\right]}{sh\frac{2|x-x'|\pi u}{\beta v_n}} \theta(|x-x'|-\delta_n) \end{aligned}$$

$$\begin{aligned} \Delta_m^* &= \sum_n \sqrt{\frac{2}{\pi}} \frac{V_{nm} \pi N_n}{\beta v_n} \Delta_n^* \int_1^\infty \frac{du}{u} \int_{-\infty}^\infty dx \int_{-\infty}^\infty dx' \theta(|x-x'| - \delta_n) \times \\ &\times \exp[-e H_0 (x^2 + x'^2)] \frac{J_0[(x^2 - x'^2) e H_0 \sqrt{u^2 - 1}]}{sh \frac{2|x-x'| \pi u}{\beta v_n}} = \\ &= \sum_n V_{nm} N_n \rho_n^{-1/2} \Delta_n^* \int_1^\infty \frac{du}{u} \int_{\delta_n'}^\infty d\zeta \exp\left[-\frac{\zeta^2}{4}(u^2 + 1)\right] \frac{I_0\left[\frac{\zeta^2}{4}(u^2 - 1)\right]}{sh[u\zeta \rho_n^{-1/2}]}, \end{aligned} \quad (11)$$

where

$$\delta_n' = (e H_0)^{1/2} \delta_n; \quad \rho_n = \frac{v_n^2 e H_0}{(2\pi T)^2}. \quad (12)$$

3. Upper critical field H_{c2} definition.

Basing on (11) it is easy to obtain the equation for the upper critical field definition in the following form:

$$-\Delta_m^* + \sum_n V_{nm} N_n \Delta_n^* \ln \frac{2\gamma \omega_D^n}{\pi T_c} + \sum_n V_{nm} N_n \Delta_n^* \left[\ln \frac{T_c}{T} - f(\rho_n) \right] = 0, \quad (13)$$

where

$$\begin{aligned} f(\rho_n) &= \rho_n^{-1/2} \int_0^\infty d\zeta \int_1^\infty \frac{du}{u sh[u\zeta \rho_n^{-1/2}]} \times \\ &\times \left\{ 1 - \exp\left[-\frac{\zeta^2}{4}(u^2 + 1)\right] I_0\left[\frac{\zeta^2}{4}(u^2 - 1)\right] \right\}. \end{aligned} \quad (14)$$

Here the following correlation was used:

$$\rho_n^{1/2} \int_1^\infty \frac{du}{u} \int_{\delta_n'}^\infty d\zeta \frac{1}{sh[u\zeta \rho_n^{-1/2}]} = \ln \frac{2\rho^{1/2}}{\delta_n' e_0}, \quad (15)$$

Equality to zero of system (13) determinant corresponds to the presence of non-zero solutions, that is the connected pair forming. The field, in the presence of which such solutions can appear, is the upper critical field H_{c2} . So the H_{c2} value is defined from the condition of system (13) solvability:

$$a f(\rho_1) f(\rho_2) + B_1 f(\rho_1) + B_2 f(\rho_2) + C = 0, \quad (16)$$

where

$$B_n = N_n V_{nn} - a \xi_c^{(n)}; \quad (n = 1, 2)$$

$$C = 1 - N_1 V_{11} \xi_T^{(1)} - N_2 V_{22} \xi_T^{(2)} + a \xi_T^{(1)} \xi_T^{(2)}; \quad a = N_1 N_2 (V_{11} V_{22} - V_{12} V_{21});$$

$$\xi_T^{(n)} = \ln \frac{2\gamma \omega_D^{(n)}}{\pi T}; \quad \xi_c^{(n)} = \ln \frac{2\gamma \omega_D^{(n)}}{\pi T_c}.$$

Condition (16) considers in the two limit cases:

a. $\rho_n \ll 1$ ($T_c - T \ll T_c$); **b.** $\rho_n \gg 1$ ($T \ll T_c$),
for which functions $f(\rho_n)$ are defined in works [14]:

$$f(\rho_n) = \frac{7}{6} \zeta(3) \rho_n - \frac{31}{10} \zeta(5) \rho_n^2 + \frac{381}{28} \zeta(7) \rho_n^3, \quad \rho_n \ll 1 \quad (17)$$

$$f(\rho_n) = \ln \frac{2(2\gamma \rho_n)^{1/2}}{e_0} - \frac{1}{\pi^2 \rho_n} \left[\zeta'(2) + \frac{\zeta(2)}{2} \ln \frac{2}{\pi^2 \gamma \rho_n} \right], \quad \rho_n \gg 1. \quad (18)$$

Case **a.** $\rho_n \ll 1$ ($T_c - T \ll T_c$)

Subject to the low electronic-phonon binding, expression (16) accepts the following form in this case:

$$B_1 f(\rho_1) + B_2 f(\rho_2) + C_a = 0,$$

where

$$C_a = \left[- (N_1 V_{11} + N_2 V_{22}) + 2a \xi_c \right] \ln \frac{T_c}{T}. \quad (19)$$

(It is supposed as usual $\xi_c^{(1)} = \xi_c^{(2)} = \xi_c = \ln \frac{2\omega_D \gamma}{\pi T_c}$.)

During obtaining of (19) equality to zero determinant of the following system of equations had been used:

$$\Delta_{mc}^* = \sum_n V_{nm} N_n \Delta_{nc}^* \xi_c, \quad (20)$$

This system defines the critical temperature T_c of superconductor. Basing on formulas (19) and (20), (17) and (12) we obtain expression for the H_{c2} value (see also [18,19]):

$$H_{c2}(T) = \frac{4\pi^2 T_c^2}{e} \left[v_1^2 \eta_1 + v_2^2 \eta_2 \right]^{-1} \frac{6}{7 \xi(3)} \theta.$$

$$\left[1 + \theta \left\{ \frac{\frac{v_1^2}{v_2^2} \eta_1 + \frac{v_2^2}{v_1^2} \eta_2}{\left(\frac{v_1}{v_2} \eta_1 + \frac{v_2}{v_1} \eta_2 \right)} \frac{31}{10} \xi(5) \left(\frac{6}{7 \xi(3)} \right)^2 - \frac{3}{2} \right\} \right], \quad (21)$$

$$\theta = 1 - \frac{T}{T_c}, \quad \eta_1 = \frac{1}{2}(1 + \eta), \quad \eta_2 = \frac{1}{2}(1 - \eta);$$

$$\eta = \frac{N_1 V_{11} - N_2 V_{22}}{\sqrt{(N_1 V_{11} - N_2 V_{22})^2 + 4N_1 N_2 V_{12} V_{21}}}$$

Coefficients η_1, η_2, η satisfy the expressions:

$$0 \leq \eta_1 \leq 1, \quad 0 \leq \eta_2 \leq 1, \quad \eta_1 + \eta_2 = 1, \quad 0 \leq |\eta| \leq 1.$$

Case **b.** $\rho_n \gg 1$ ($T \ll T_c$)

Basing on equation (16) and using (12) and (18) we obtain for the $H_{c2}(T)$ value the following expression in this case:

$$H_{c2}(T) = \frac{2\gamma\omega_D^2}{ev_1v_2} \exp(2 - \Sigma), \tag{22}$$

where

$$\Sigma = \eta^\pm \pm \sqrt{((\ln \lambda - \eta^{(-)})^2 + \frac{4N_1 N_2 V_{12} V_{21}}{a^2} - 4F(\rho_0))}, \tag{23}$$

$$\eta^\pm = \frac{1}{a}(N_1 V_{11} \pm N_2 V_{22}), \quad \lambda = \frac{v_1}{v_2},$$

$$F(\rho_0) = \frac{1}{\rho_0} [P(\ln \rho_0)^2 + Q \ln \rho_0 + R], \tag{24}$$

$$\rho_0 = \frac{ev_1v_2}{4\pi^2 T^2} H_{c2}(0). \tag{25}$$

$$H_{c2}(0) = \frac{2\gamma\omega_D^2}{ev_1v_2} \exp(2 - \alpha), \tag{26}$$

$$\alpha = \eta^{(+)} \pm \sqrt{(\ln \lambda - \eta^{(-)})^2 + \frac{4N_1 N_2 V_{12} V_{21}}{a^2}}, \tag{27}$$

$$P = \frac{\zeta(2)}{4\pi^2} \left(\lambda + \frac{1}{\lambda} \right), \tag{28}$$

$$Q = \frac{1}{2\pi^2} \left(\lambda + \frac{1}{\lambda} \right) \left[\frac{\zeta(2)}{2} \ln(x_1 x_2) - \zeta'(2) \right] + \frac{\zeta(2)}{2\pi^2} \left[\varepsilon^{(+)} - \left(\lambda + \frac{1}{\lambda} \right) \xi_T \right], \quad x_1 = \frac{8\gamma}{e_0^2}, \quad x_2 = \frac{\pi^2 \gamma}{2}; \quad (29)$$

$$R = \frac{\zeta(2)}{4\pi^2} \left\{ \left(\lambda + \frac{1}{\lambda} \right) \left[\ln x_1 \ln x_2 - (\ln \lambda)^2 \right] - \left(\lambda - \frac{1}{\lambda} \right) \ln \lambda \ln \frac{x_1}{x_2} \right\} - \frac{\xi'(2)}{2\pi^2} \left[\left(\lambda + \frac{1}{\lambda} \right) \ln x_1 + \left(\lambda - \frac{1}{\lambda} \right) \ln \lambda \right] + \frac{1}{\pi^2} \left[\frac{\xi(2)}{2} \ln x_2 - \zeta'(2) \right] \times \left[\varepsilon^{(+)} - \left(\lambda + \frac{1}{\lambda} \right) \xi_T \right] - \frac{\zeta(2)}{2\pi^2} \ln \lambda \left[\varepsilon^{(-)} - \left(\lambda - \frac{1}{\lambda} \right) \xi_T \right], \quad \varepsilon^{(\pm)} = \frac{1}{\alpha} \left(\lambda N_2 V_{22} \pm \frac{1}{\lambda} N_1 V_{11} \right). \quad (30)$$

In our case (T close to zero) the expression can be adduced to the form:

$$H_{c2}(T) = H_{c2}(0) \left[1 + \frac{2}{S v(\lambda)} F(\rho_0) \right], \quad (31)$$

where

$$v(\lambda) = \sqrt{(\ln \lambda - \eta^{(-)})^2 + \frac{4N_1 N_2 V_{12} V_{21}}{\alpha^2}}, \quad S = \pm 1 \quad (32)$$

or

$$\frac{H_{c2}(T \rightarrow 0)}{H_{c2}(0)} = 1 + \frac{16\gamma}{e_0^2 \pi^2} \left(\frac{T}{T_c} \right)^2 e^{S v(\lambda) - S v(1)} \left\{ \left(\lambda \gamma^+ + \frac{1}{\lambda} \gamma^- \right) \left[\zeta'(2) + \zeta(2) \ln \frac{4T}{e_0 \pi T_c} + \frac{S}{2} v(\lambda) - \frac{S}{2} v(1) \right] + \frac{\zeta(2)}{2} \left(\lambda \gamma^+ - \frac{1}{\lambda} \gamma^- \right) \ln \lambda \right\}, \quad (33)$$

$$\gamma^\pm = \frac{1}{2} \left[1 \pm \frac{\eta^- - \ln \lambda}{S v(\lambda)} \right], \quad H_{c2}(0) = \frac{\pi^2 T_c^2 e_0^2}{2\gamma e v_1 v_2} \exp v[(1) - v(\lambda)]. \quad (34)$$

Expression (33) can also be obtained from formula (33) of work [18].

Let's consider simplified case $V_{22}=0$. Here on the base of definitions (24) and (32) we obtain:

$$\eta^{(\pm)} = -\frac{\lambda_{11}}{\lambda_{12} \lambda_{21}}, \quad \lambda_{11} = N_1 V_{11}, \quad \lambda_{12} = N_2 V_{12}, \quad \lambda_{21} = N_1 V_{21},$$

$$v(\lambda) = \sqrt{\left(\ln \lambda + \frac{\lambda_{11}}{\lambda_{12}\lambda_{21}}\right)^2 + \frac{4}{\lambda_{12}\lambda_{21}}},$$

$$\gamma^\pm = \frac{1}{2} \left[1 \mp \frac{\frac{\lambda_{11}}{\lambda_{12}\lambda_{21}} + \ln \lambda}{S v(\lambda)} \right]. \quad (35)$$

where

$$\lambda_{11} = N_1 V_{11}, \lambda_{12} = N_2 V_{12}, \lambda_{21} = N_1 V_{21}$$

For $S=1$ and $V_{22}=0$ the expression for $H_{c2}(T)$ (33) turns into corresponding expression of work [8]. For the temperature close to the value T_c in the limit case $V_{22}=0$ we obtain:

$$\frac{H_{c2}(T \rightarrow T_c)}{H_{c2}(0)} = \frac{8\gamma v_1 v_2}{e_0^2 [v_1^2 \eta_1 + v_2^2 \eta_2]} \exp(v(\lambda) - v(1)) \frac{6}{7\zeta(3)} \times$$

$$\times \left(1 - \frac{T}{T_c}\right) \left\{ 1 + \left(1 - \frac{T}{T_c}\right) \left[\frac{\frac{v_1^2}{v_2^2} \eta_1 + \frac{v_2^2}{v_1^2} \eta_2}{\left(\frac{v_1}{v_2} \eta_1 + \frac{v_2}{v_1} \eta_2\right)^2} \frac{31}{10} \zeta(5) \left(\frac{6}{7\zeta(3)}\right)^2 - \frac{3}{2} \right] \right\}, \quad (36)$$

where

$$\eta_{1,2} = (1 \pm \eta) / 2, \quad \eta = \lambda_{11} / \lambda_{12} \lambda_{21} v(1). \quad (37)$$

Assuming in formulas (33)-(36) $v_1 = v_2$ we obtain corresponding ratios for usual one-band superconductor. These ratios have the form:

$$\frac{H_{c2}(T \rightarrow 0)}{H_{c2}(0)} = 1 + \frac{16\gamma}{\pi^2 e_0^2} \left(\frac{T}{T_c}\right)^2 \left\{ \zeta(2) \ln \frac{T}{T_c} + \zeta'(2) + \zeta(2) \ln \frac{4}{\pi e_0} \right\}, \quad (38)$$

$$\frac{H_{c2}(T \rightarrow T_c)}{H_{c2}(0)} = \frac{8\gamma}{e_0^2} \frac{6}{7\zeta(3)} \left(1 - \frac{T}{T_c}\right) \left\{ 1 + \left(1 - \frac{T}{T_c}\right) \left[\frac{31}{10} \zeta(5) \left(\frac{6}{7\zeta(3)}\right)^2 - \frac{3}{2} \right] \right\}. \quad (39)$$

and coincide with the results of works [13,14].

4. The discussion of the results.

We obtained equation (16), on the base of which the value of the upper critical field in the two-band system can be calculated in the whole temperature interval $0 \leq T < T_c$. The analytic solutions of this equation were obtained for $T \rightarrow T_c$ (21) and $T \rightarrow 0$ (33). It is easy to notice that H_{c2} depends on the correlations of the speeds v_1 and v_2 of the electrons on the Fermi surface, and on the constants of the electron-phonon interaction λ_{nm} .

If $H_{c2}^0(0)$ and T_{c0} are introduced (upper critical field and critical temperature of the one-band low-temperature superconductor), on the base of (34) we obtain:

$$H_{c2}(0)/H_{c2}^0(0) = (T_c/T_{c0})^2 \frac{v_1}{v_2} \exp((v_1 - v_2)\lambda). \quad (40)$$

The numerical estimations (40) allow us to make the conclusion, that the upper critical field of two-band superconductors for $T=0$ can exceed the value of $H_{c2}^0(0)$ for usual superconductors by two-three orders. These big values $H_{c2}(0)$ are provided by high T_c and by ratio $v_1/v_2 > 1$ or $\gg 1$.

The dependence $H_{c2}(T)/H_{c2}(0)$, which was obtained on the base of formulas (33) and (34) of the value H_{c2} for $T \sim 0$ and $T \sim T_c$ correspondingly and their extrapolations, is given in

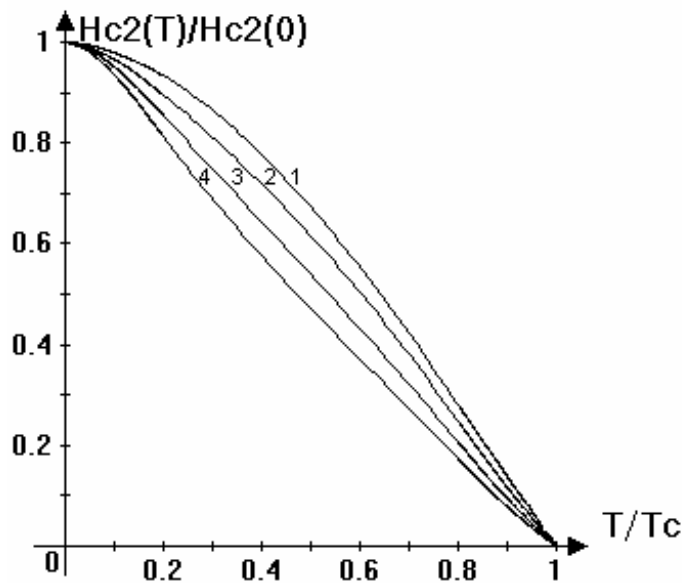


Fig.1. The temperature dependence $H_{c2}(T)/H_{c2}(0)$ at $\lambda_{11} = 0,2$, $\lambda_{12} = 0,3$ and values $v_1/v_2 = 1, 2, 3$ and 4 (curves 1-4 correspondingly)

It is easy to see, that with growth of v_1/v_2 , the curvature in this dependence changes. Curves 3 and 4 give the curvature, which was observed during the experiment in a row of oxidation ceramics. So if there are heavy carriers in the second band (low speeds on the Fermi surface), the two-band model qualitatively describes the behavior of H_{c2} as a function of temperature in these materials.

The above obtained allow us to make the conclusion about qualitative describing of the experimental data by the behavior of the ratio $H_{c2}(T)/H_{c2}(0)$ as a function of temperature [2] in the intermetallic compound MgB_2 . This theory gives the big values of $H_{c2}(0)$ in two-band system in comparison with one-band case. For obtaining of the quantitative accordance with the experimental data it is necessary to know the theory parameters conformably to MgB_2 , which should be evaluated from the existing experimental data on the base of two-band model.

Acknowledgement

The author wishes to thank Prof. T. Mishonov for the interest and discussions concerning the theory of two-band superconductors and for the submitted references.

References

- [1] Nagamatsu J., Nakagawa N. et al., *Natura* 410, 63 (2001).
- [2] Canfield P. C., Bud'ko S.L., Finnemore D. K., *Physica C*, 385, 1 (2001).
- [3] Chen X. K., Konstantinovich M. J. et al., *Phys. Rev. Lett.* 87, 157002 - 1.
- [4] Tsuda S., Yokoya T. et al, *Phys. Rev. Lett.* 87, 177006-1 (2001).
- [5] Moskalenko V. A., *Fiz. Met. Metalloved*, 503 (1959); *Phys. Met. and Metallog.* 8, 25 (1959).
- [6] Suhle H., Matthies B. T., and Walker L. R., *Phys. Rev. Lett.*, 3, 552 (1959).
- [7] Palistrant M.E., arXiv : cond-mat / 0305496 (2003).
- [8] Moskalenko V. A., Palistrant M. E. and Vakalyuk V. M., *Usp. Fiz. Nauk*, 161, 155 (1991); *Sov. Phys. Usp.* 34, 717 (1991); arXiv : cond-mat / 0309671.
- [9] Kon L. Z., arXiv : cond-mat / 0309707 (2003).
- [10] Mishonov T., Penev E., Indekeu J. O. and Pokrovsky V.I., arXiv: cond-mat / 0209342 (2003); *Phys. Rev. B* 68, 104517 (2003).
- [11] Mishonov T., Drechsler S. and Penev E., *Modern Physics Letters B*, 17, 755 (2003).
- [12] Abrikosov A.A., *Zh. Eksp. Teor. Fiz.* 32, 442 (1957).
- [13] Gor'kov L. P., *Zh. Eksp. Teor. Fiz.* 37, 833 (1959).
- [14] Maki K. and Tsuzuki T., *Phys. Rev. A* 139, 868 (1965).
- [15] Moskalenko V.A., *Zh. Eksp. Teor. Fiz.* 51, 1163 (1966).
- [16] Gor'kov L. P., *Zh. Eksp. Teor. Fiz.* 36, 1918 (1959).
- [17] Moskalenko V.A., Palistrant M.E., *Dokl. Akad. Nauk SSSR*, 162, 532, 1965; *Zh. Exp. Teor. Fiz.* 49, 770, 1965; *Sov. Phys. JETP* 22, 536 (1966).
- [18] Palistrant M. E. and Dedju, *Phys. Lett. A* 24, 537 (1967); *Investigation on the Quantum Theory of Many- Particle Systems* (Kishinev, Stiinta, 1969), p.55 [in Russian].
- [19] Moskalenko V. A. and Palistrant M.E., *Statistical Physics and Quantum Field Theory* M. , Nauka, 1973 p.262 [in Russian].