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Ginzburg-Landau Theory of Specific Heat Anomaly of High-T_c Superconductors in Magnetic Field

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The change in specific heat by the application of magnetic field ($B_a \sim 1\ T$) in the case of the high-T_c superconductors is examined phenomenologically by the Ginzburg-Landau theory of anisotropic type-II superconductors. The observed large reduction of specific heat anomaly just below the superconducting transition is explained quantitatively. We have obtained the expression for the change in specific heat in a magnetic field (ΔC) for any general orientation of B_a with respect to the crystallographic c-axis. We also present the result for a polycrystalline sample. ΔC is shown to be linear in $(B_a/T_c)[t/(1-t)]$ for temperatures slightly below T_c, where $t = T/T_c$. The slope of this linear behaviour is found to be related to the anisotropy of the effective mass.

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1.INTRODUCTION

The origin of the unusual magnetic field dependence of specific heat in the high-T_c superconductors (HTSC) has been the subject of several recent investigations. Experiments on HTSC show that the specific heat anomaly near the superconducting transition temperature T_c is reduced in amplitude with negligible downward shift in temperature by the application of magnetic field $B_a(\sim 1\text{T})$ [1-5]. The above mentioned behaviour is distinctly different from the conventional type-II superconductors. It was shown recently that the unusual magnetic field dependence of the specific heat anomaly in HTSC can arise due to a very general reason on the basis of 3-dimensional description of the phenomenological Ginzburg-Landau (GL) theory of anisotropic type-II superconductors [6]. The field dependence of the specific heat for $B_a \parallel c$-axis and $B_a \perp c$-axis could be explained quantitatively by the phenomenological GL-theory. The anisotropy in the "field dependences" was shown to be directly related to the anisotropy of the effective mass $\gamma = (m_c/m_{ab})^{1/2}$. Here, m_c and m_{ab} are the components of the dimensionless effective mass tensor parallel and perpendicular to the c-axis, respectively.

2.PHENOMENOLOGICAL THEORY

The HTSC are extreme type-II superconductors with the GL-parameter of the order of 10^2. For $B_a \sim 1$ T, these superconductors remain in the mixed state. It was argued that the GL-theory in the London limit is the appropriate description of this mixed state for $B_a \sim 1$ T and temperatures up to fraction of a Kelvin below T_c [6]. Here, we make use of the anisotropic formulation of the London limit developed by Kogan and coworkers [7,8], although there is limitation, as has been pointed out recently [9]. Using this formalism Reeves et al. [10] has obtained the following approximate form of H:

$$H = \frac{B}{\mu_0} + \alpha m^{1/2} \lambda_m^{-2} \ln(B_{c2}/B). \quad (1)$$

where $m = m_{ab} sin^2\theta + m_c cos^2\theta$, λ_m is the mean penetration depth $\lambda_m = (\lambda_{ab}^2 \lambda_c)^{1/3}$, and $\alpha = \phi_0/8\pi\mu_0$. θ is the angle between the $c-$axis and $\mathbf{B}$. Proceeding in the manner as given in reference [6], the change in specific heat by the application of magnetic field $\Delta C = C(0,T) - C(\mathrm{B_a}, T)$ can be shown to be given by:

$$\Delta C = \frac{B}{T_c} \frac{2\alpha m^{1/2}}{\lambda_m(0)} \frac{t}{(1-t)} + \mathcal{O}[(\frac{L}{\lambda_m})^4]. \quad (2)$$

Here $t = T/T_c$. We can replace B by $B_a = \mu_0 H$ in Eq.6 by noting that the magnetization in the mixed state is very small compared to B_a. This gives ΔC for any general orientation of $\mathbf{B_a}$ with respect to the $c-$axis. The term of the order of $(L/\lambda_m)^4$ is negligible and also not reliable [6]. We can therefore, ignore it.

We next examine the polycrystalline case. In several instances, preparation process of the HTSC results in preferential orientation of the $c-$axis. Here, however, we assume random orientation of the grains in the polycrystalline sample and carry out the average over a spherical shell as used by Reeves et al. [10] to obtain:

$$< \Delta C >= \frac{B_a}{T_c} \frac{t}{(1-t)} \frac{\alpha\Theta}{\lambda_m^2(0)} \quad (3)$$

where,

$$\Theta = \gamma^{-1/3}[\gamma + \frac{0.5}{\sqrt{(\gamma^2-1)}} \ln(\frac{\gamma + \sqrt{(\gamma^2-1)}}{\gamma - \sqrt{(\gamma^2-1)}})]. \quad (4)$$

It is seen from Eq.3 that ΔC increases rapidly as $T \rightarrow T_c$ which gives rise to the observed reduction in the amplitude of the specific heat anomaly. We note that $< \Delta C >$ is linear in $(B_a, T_c)[t/(1-t)]$. The slope of this linearity is related to the anisotropy of the effective mass. It is therefore, possible to get reasonable estimates of γ from the specific heat measurement in magnetic field on polycrystalline HTSC. We analyse the specific heat data for polycrystalline $YBa_2Cu_3O_7$ taken in a field of 7 Tesla by Phillips et al. [1]. The data is obtained from fig.3 of this reference. $< \Delta C >$ versus $(B_a/T_c)[t/(1-t)]$ is then least squares fitted to a straight line for $0.971 < t < 0.988$. Here T_c=91.2 K. We obtain the anisotropy of effective mass to be $\approx$ 4.0 by taking $\lambda_m(0)$=2066 Å [6]. This value of γ is in reasonable agreement with the earlier reported value [5].

REFERENCES

1. N.E.Phillips et al., Physica **148B**, 360 (1987).
2. R.A.Fisher, J.E.Gordon, S.Kim, N.E.Phillips, and A.M.Stacy, Physica (Amsterdam) **153 – 155C**, 1092 (1988).
3. M.B.Salamon et al., Phys. Rev. B **38**, 885 (1988); S.E.Inderhees, M.B.Salamon, J.P.Rice, and D.M.Ginsberg, Phys. Rev. Lett. **66**, 232 (1991).
4. E.Bonjour et al., Physica **166C**, 451 (1990); E.Bonjour, R.Calemczuk, J.Y.Henry and A.F.Khoder, Physica B **165 + 166**, 1343 (1990).
5. S.B.Ota, V.S.Sastry, E.Gmelin, P.Murugaraj, and J.Maier, Phys. Rev. B **43**, 6147 (1991).
6. S.B.Ota, Phys. Rev.B **43**, 1237 (1991).
7. V.G.Kogan, Physica C **162 – 164**, 1689 (1989) and the references therein.
8. L.J.Campbell, M.M.Doria, and V.G.Kogan, Phys. Rev. B **38**, 2439 (1988).
9. Z.Hao and J.R.Clem, Phys. Rev. Lett. **67**, 2371 (1991).
10. M.E.Reeves et al., Phys.Rev.B **40**, 4573 (1989).