PRAMANA
—journal of
physics

Vol. 50, No. 4,
May 1998
pp. 459–462

Magnetization of high-T_c superconductors

B KALTA and K K NANDA*
Sonepur College, Subarnapur, India
*Institute of Physics, Bhubaneswar 751 005, India
E-mail: nanda@iopb.stpbh.soft.net

MS received 19 July 1997; revised 28 January 1998

Abstract. We have tried to understand the field dependence of magnetization of high temperature superconductors in the light of phenomenological theory. Especially, the field dependence of $dM/d\ln B$ of polycrystalline Bi(2212) is understood by incorporating the overlap of vortices in the London theory.

Keywords. High-T_c superconductors; magnetization; phenomenological theory.

PACS Nos 74.25; 74.20

The magnetic properties of high temperature superconductors (HTSCs) in magnetic fields are very unusual near the transition temperature T_c and are different for different HTSCs. Near T_c, the magnetization (M) of Y(123) is proportional to $(T - T^*)^2$, where T^* is almost field independent and close to T_c [1, 2]. It has also been observed that the magnetization of Y(123) is approximately logarithmic in B_a in the reversible region and can be understood by using 3D description of the London theory [3–5]. It has also been applied to understand the temperature dependence of specific heat in magnetic field [6], whereas, the field dependence is understood by incorporating the overlap of vortices in the London theory [7]. Incorporating the overlapping of vortices in the London theory the magnetization for 3D superconductors can be written as [7]

$$M = M_L = \frac{B - H}{4\pi} = -\frac{\phi_0}{32\pi^2\lambda_{\text{eff}}^2}\ln\left(\frac{B_{c2}}{B_a}\right) = -\frac{\phi_0 f^2}{32\pi\lambda^2}\ln\left(\frac{B_{c2}}{B_a}\right). \tag{1}$$

This is similar to the result obtained from the variational model [8] in the London limit. The temperature dependence of penetration depth and the upper critical field is given by [9]

$$\lambda(T) = \frac{\lambda_0}{\sqrt{2}(1 - t)^\beta} \quad \text{and} \quad B_{c2} = B_{c20}(1 - t)^{2\nu}, \tag{2}$$

where $t = T/T_c$. The ν is 1/2 in the mean field region and 2/3 in the critical region. Similarly the β takes the value as 1/2 and 1/3 in the mean field and critical region respectively.

The field dependence of magnetization according to different models are shown in figure 1. It is noted that the vortex overlapping mechanism at low fields gives results

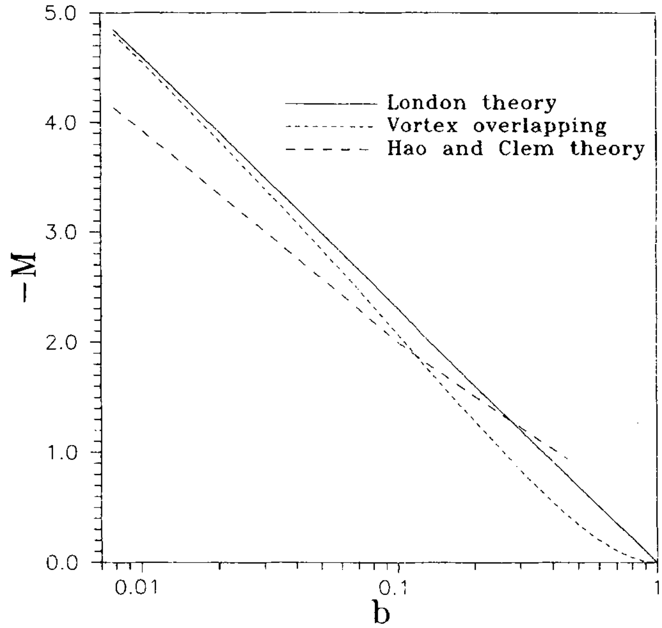

Figure 1. The magnetization (in units of $\phi_0/32\pi^2\lambda^2$) vs b.

which are in between that obtained from the usual London theory and the variational approach proposed by Hao *et al* [7] and the magnetization is approximately logarithmic in B_a. Near B_{c2} or close to T_c, the logarithmic term in eq. (1) can be expanded as $(1-(B_a/B_{c2})$. So the magnetization behaves as $(B_{c2}-B_a)^2$ or $(T_c-T)^2$. If the upper critical field is large, the change on T_c with magnetic field is little as observed experimentally [1,2].

The magnetic properties of Bi(2212) are different from Y(123). In the intermediate field range, the $-4\pi M$ vs $\ln B_a$ curve of Bi(2212) single crystal is not linear as predicted from the London theory. The variation in the case of single crystal [10,11] is different from the polycrystalline case [12]. According to the mean field theory developed by Koshelev [13] (from eq. C11), the field dependence of the slope $\mathrm{d}M/\mathrm{d}\ln B$ can be written as

$$\frac{\mathrm{d}M}{\mathrm{d}\ln B}=\frac{\phi_0}{32\pi^2\lambda^2(T)}\left[1+2\frac{B_a}{B_{c2}}\ln\left(\frac{B_a}{\eta e B_{c2}}\right)\right] \quad \text{with} \quad \eta=0.35. \tag{3}$$

Whereas, according to the vortex overlapping mechanism [7], it is given by

$$\frac{\mathrm{d}M}{\mathrm{d}\ln B}=\frac{\phi_0}{32\pi^2\lambda^2(T)}\left[1-\frac{B_a}{B_{c2}}\ln(eB_a/B_{c2})\right]. \tag{4}$$

Shown in figure 2 is the $\mathrm{d}M/\mathrm{d}\ln B$ versus B_a. The dashed line represents the Koshelev's result and the solid line represents the vortex overlapping result. It is noted from this figure that both mean field theory and vortex overlapping mechanism predicts different field dependence for $\mathrm{d}M/\mathrm{d}\ln B$. By inspection, it can be concluded that the latter would be useful to understand the field dependence in case of polycrystalline sample. However,

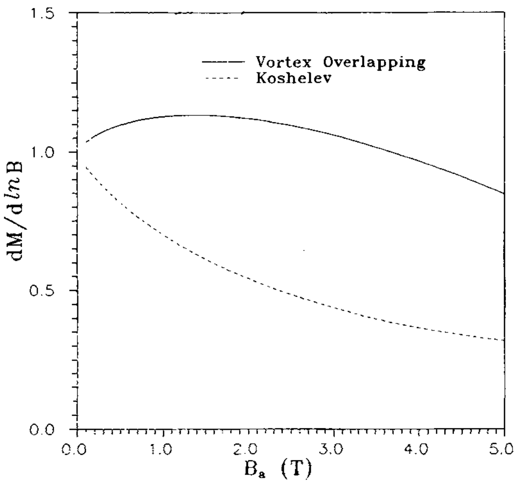

Figure 2. $\mathrm{d}M/\mathrm{d}\ln B_a$ (in units of $\phi_0/32\pi^2\lambda^2$) versus B_a. For the solid line we have taken $B_{c2} = 10$ and for dashed line $B_{c2} = 20$ T.

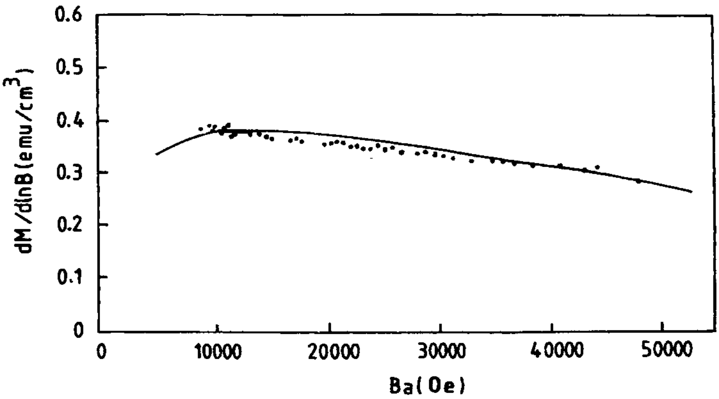

Figure 3. The field dependence of $\mathrm{d}M/\mathrm{d}\ln B_a$ of a polycrystalline Bi(2212) sample at $T = 55$ K. The data are taken from figure of ref. [12]. The solid line is a theoretical fit according to eq. (4) with parameters $\lambda = 4017$ Å and $B_{c2} = 100$ T.

Genoud *et al* [12] have claimed that the polycrystalline data can be fitted to Koshelev's prediction quantitatively. In this context, it is worth pointing out that eq. (C11) and (C12) of ref. [13] predicts similar field dependence for $\mathrm{d}M/\mathrm{d}\ln B$. Hence, the claim of Genoud *et al* is not justified. In order to verify the overlapping mechanism quantitatively, we have taken the data of Genoud *et al* [12] for a polycrystalline sample and compared with eq. (4) as shown in figure 3. The solid line is a fit to the data according to eq. (4) with $\lambda = 4017$ Å and $B_{c2} = 100$ at $T = 55$ K. These values are reasonably in good agreement with earlier reported results implying that the field dependence of $\mathrm{d}M/\mathrm{d}\ln B$ can be understood by incorporating the overlap of vortices in the London theory.

In conclusion, the field dependence of $\mathrm{d}M/\mathrm{d}\ln B$ of polycrystalline Bi(2212) is understood by incorporating the ovarlap of vortices in the London theory.

References

[1] K S Athreya *et al*, *Phys. Rev.* **B38**, 11846 (1988)
[2] U Welp, W K Kwok, G W Crabtree, K G Vandevoort and J Z Liu, *Phys. Rev. Lett.* **62**, 1908 (1989); *Physica* **C162–164**, 735 (1989)
[3] V G Kogan, M M Fang and S Mitra, *Phys. Rev.* **B38**, 11958 (1988)
[4] S Mitra *et al*, *Phys. Rev.* **B40**, 2674 (1989)
[5] G Triscone *et al*, *Physica* **C224**, 263 (1994)
[6] S B Ota, *Phys. Rev.* **B43**, 1237 (1991)
S B Ota, K K Nanda and S N Behera, *Physica* **B194–196**, 1387 (1994)
[7] K K Nanda, *Physica* **C245**, 341 (1995)
[8] Z Hao, J R Clem, M W McElfresh, L Civale, A P Malozemoff and F Holtzberg, *Phys. Rev.* **B43**, 4844 (1991)
Z Hao and J R Clem, *Phys. Rev. Lett.* **67**, 2371 (1991)
[9] L N Bulaevskii, V L Ginzberg and A A Sobyanin, *Physica* **C152**, 378 (1988)
[10] M Tuominen, A M Goldmann, Y Z Chang and P Z Jiang, *Phys. Rev.* **B42**, 412 (1990)
[11] V G Kogan, M Ledvij, A Yu Simonov, J H Cho and D C Johnston, *Phys. Rev. Lett.* **70**, 1870 (1993)
[12] J-Y Genoud, G Triscone, A Junod, T Tsukamoto and J Muller, *Physica* **C242**, 143 (1995)
[13] A E Koshelev, *Phys. Rev.* **B50**, 506 (1994)