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Correction Between B and H, and the Analysis of the Magnetization Into Uniaxial Superconductor in the Limit at Large Values of B

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Abstract

Using the London theory we obtain a correction between the direction of the magnetic induction $\vec{B}$ and the applied magnetic field $\vec{H}$ in superconductors with uniaxial anisotropy when the Ginsburg-Landau constant is not so large. We make one analysis of the magnetization as function of angle α.

Key-words: Superconductor; Vortex; Magnetization.

In the high-Tc superconductors one of the properties is the large value of the Ginsburg-Landau constant [1, 2], κ. It allows that in first approximation the magnetic induction be equal to applied magnetic field. In this work we make a study of the variation of the direction between $\vec{B}$ and $\vec{H}$ from several values of κ. This variation enables us evaluate the free energy as function of α. The fig. (1) shows the free energy in the limit of large magnetic induction as function of α, for some values of Ginsburg-Landau constantes. θ and α are, respectively the angle between $\vec{B}$ and $\vec{H}$ with axis of symmetry ($\vec{z}$).

In this paper our calculation is in the context of anisotropic London theory, where the total energy is given by [1]

$$F_{total} = (1/8\pi) \int dv (\lambda_{jk}^2 J_j J_k + h \cdot h) \; , \tag{1}$$

the supercurrents kinetic energy is determined by the local magnetic field $h(\vec{r})$ through Ampères's Law. For a superconductor with uniaxial anisotropic along the $\vec{z}$ axis the penetration length tensor is

$$\lambda = \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_1 & 0 \\ 0 & 0 & \lambda_3 \end{pmatrix} \tag{2}$$

in the crystal's frame of reference.

We can determine the free energy of the vortex system by [1]

$$f = (B/\kappa_z)\left(\varepsilon(\kappa_z, \gamma, \vartheta) + V(B\kappa_z, \gamma, \vartheta, \rho, \phi) - B\kappa_z\right) + B^2 \; . \tag{3}$$

This expression comes from contribution of interaction of lines energy of coreless vortices plus a Gaussian model for the vortex lines. The multiplicative B term indicates that the free energy per volume should be proportional to the density of vortex lines. The contribution of the self-energy, $(B/\kappa_z)\varepsilon$, does not depend on the unit cell parameters, ρ and ϕ, nor on the magnetic induction, B. The interline term $(B/\kappa_z)V$, which describes the interaction among vortex lines, depends on the magnetic induction B, and on the arrangement of the vortex lines in the space, described by ρ and ϕ. Here, we have $\kappa_z = \kappa\gamma^{2/3}$, where γ is the parameter $m_1/m_3 < 1$ that determines the anisotropy in the London theory. All numerical results in this paper are obtained for a fixed value of anisotropic, namely $\gamma = 0.02$ which is the typical anisotropy of $YBa_2Cu_30_7$. ρ is the ratio between the unit cell sides, L_1 and L_2. ϕ is the angle between L_1 and L_2.

At the limit of the large κ the magnetization is enough small, so we can take the approximation that $B = H$ and $\theta = \alpha$. However, for values of κ not so large this approximation is not correct. In this point, we can use the thermodynamic relation, what in reduced units is given by $H = (1/2)\partial f/\partial B$, in eq. (3), and we find,

$$\begin{aligned} H_x &= B_x + (1/2\kappa)\partial(Bf)/\partial B_x \\ H_z &= B_z + (1/2\kappa)\partial(Bf)/\partial B_z \; . \end{aligned} \tag{4}$$

At the limit of extremely large vortex density B, the total free energy follows as [1]

$$f = (B\Gamma/2\kappa_z\gamma)\log(H_{c2}\eta/B) \tag{5}$$

where $\Gamma(\vartheta)^2 = \cos^2\vartheta + \gamma\sin^2\vartheta$; $H_{c2} = \kappa_z\gamma/\Gamma$; $\eta = \gamma e^{2ce}A^2/4\sigma\Gamma^4C^2$; the auxiliary functions are

$$\begin{aligned} A &= \left(\frac{\Gamma(\vartheta) + |\cos(\vartheta)|}{\sqrt{\gamma}(1) + |\cos(\vartheta)|}\right)^{|\cos(\vartheta)|/\Gamma(\vartheta)} \; ; \\ C &= \prod_{s=1}^{\infty}\left(1 - 2\cos(\chi_s)e^{-\sigma\Gamma(\vartheta)_s} + e^{-2\sigma\Gamma(\vartheta)}\right) \; . \end{aligned}$$

The above functions depend on $\sigma = 2\pi\sin(\phi)/\rho$, $\chi = 2\pi\cos(\phi)/\rho$ and the Euler constant ce. At this limit, we take the unit cell parameters found on ref. [2]. Through eqs. (4) and (5), we find, after some simplification,

$$B_x = H_x - (1/2\kappa)\left(\sin(\vartheta)\partial(Bf)/\partial B + \cos(\vartheta)\partial f/\partial\vartheta\right) \tag{6}$$

$$B_z = Hz - (1/2\kappa)\left(\cos(\vartheta)\partial(Bf)/\partial B - \sin(\vartheta)\partial f/\partial\vartheta\right) \tag{7}$$

where $H_x = H\sin\alpha$, $H_z = H\cos\alpha$, $B_x = B\sin\theta$, and $B_z = B\cos\theta$.

We made a iterative program such that we obtained a correction between the orientation of $\vec{B}$ and $\vec{H}$. We assume that the intensity of $\vec{B}$ and $\vec{H}$ are equal in first approximation, and we varied the angle θ and found the angle α and a new value to $\vec{B}$. The effects due to the superconductor shape are not treatet here, we consider a superconductor with no diamagnetization factor, and the external magnetic field is obtained from $\vec{B} = \vec{H} + 4\pi\vec{M}$.

We found a interesting behavior for magnetization as function of α and we observe two angle where there are two distinct direction of magnetism for $\kappa = 50$. We observe that all κ evaluate here show a maximum value of magnetization around $\alpha = 70^0$. We understading it as due the interaction energy because in this limit it gives important portion to total energy and there is a local minimum energy in this angle [2]. We can also think that it is the angle that vortex chains appear [2].

The correction between α and θ gives a possibility of evaluate of the Gibbs Function for this system. If we writte the free energy with distinct directions for vortex lines [3], we will enable the coexisting of the orientation of the vortex. So, we will be enable to understand what was showed by A. Sudbo at al. [4]. It can explain about the decoration figures of the vortex system found by C.A. Bolle et al. [5]

Figure Captions

Fig. 1: In this figure we show the free energy as function of α for several values of κ, no so larges.

Fig. 2: In this figure we show the magnetization as function of the α for several values of κ.

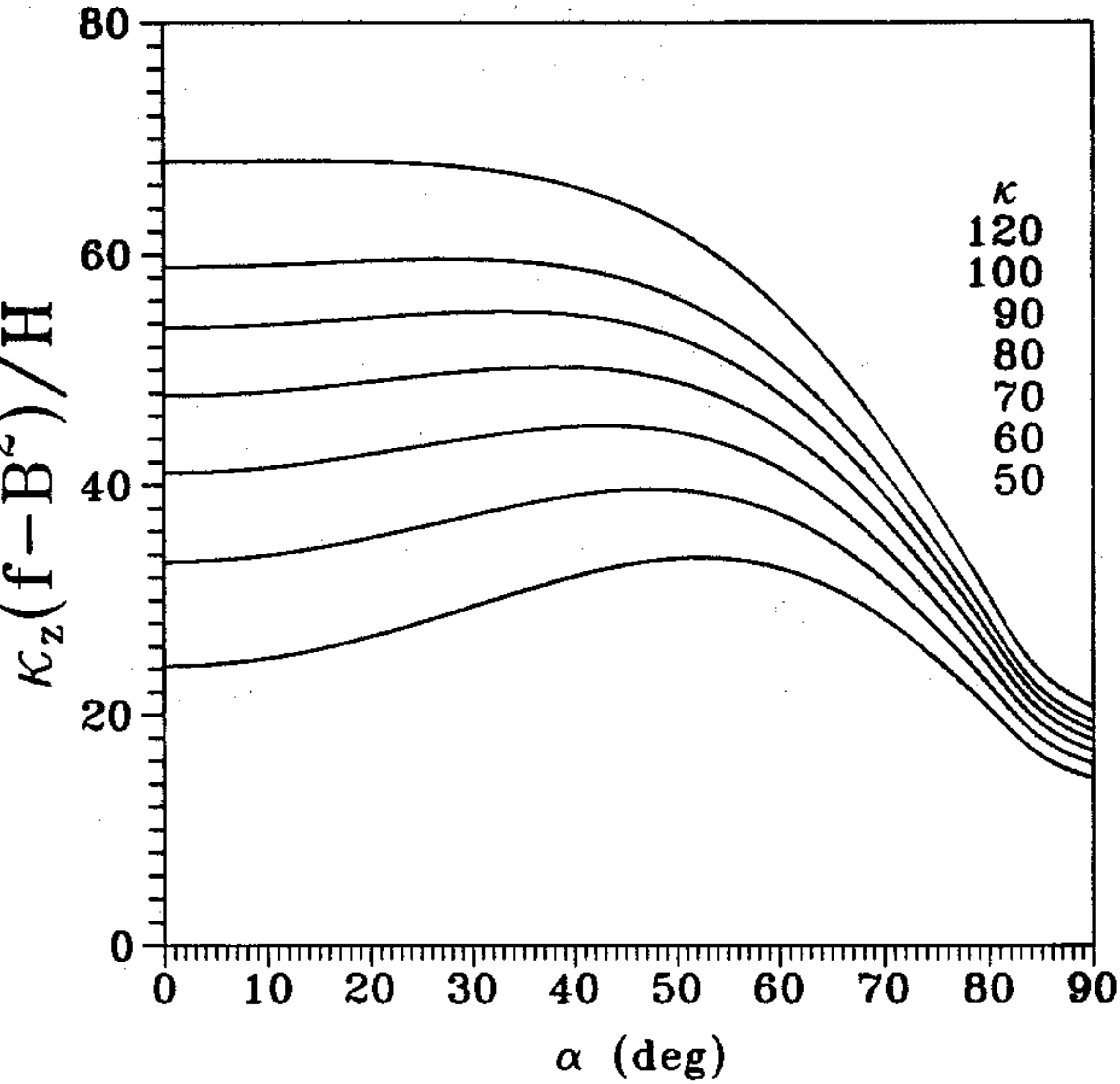
80
60
40
20
0
0 10 20 30 40 50 60 70 80 90
$\kappa_z(f-B^2)/H$
α (deg)
κ
120
100
90
80
70
60
50

Figure 1

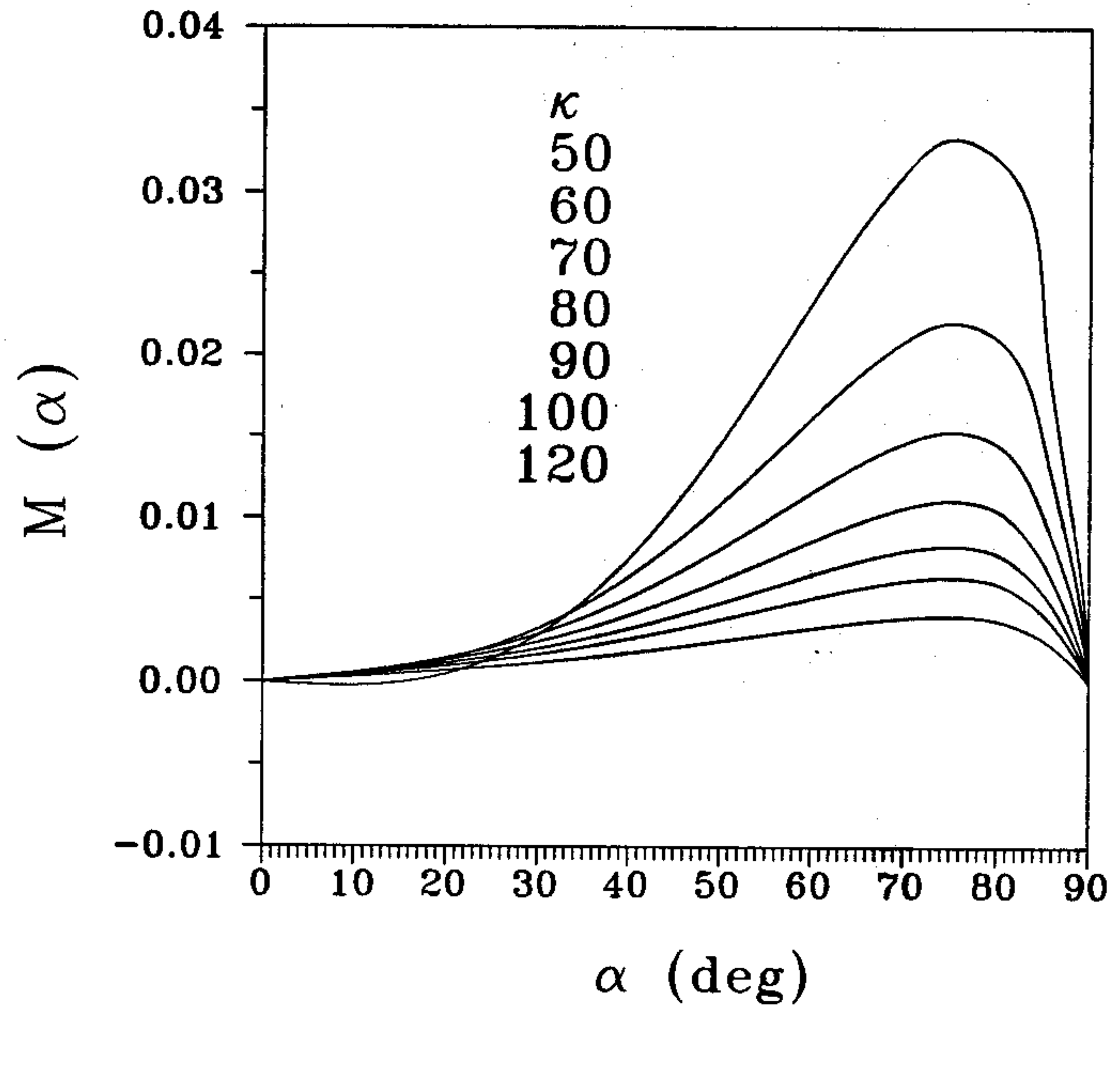
0.04
0.03
0.02
0.01
0.00
−0.01
M (α)
κ
50
60
70
80
90
100
120
0
10
20
30
40
50
60
70
80
90
α (deg)

Figure 2

References

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