2012

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Recommended Citation

Kossler, W. J., Greer, A. J., Harshman, D. R., Stronach, C. E., Shockley, A. C., & Shinn, M. (2012). Effects of Vortex Pinning on the Temperature Dependence of the Magnetic Field Distributions in Superconductors. Physics Procedia, 30, 245-248.

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 30 (2012) 245 – 248

Physics Procedia

12th International Conference on Muon Spin Rotation, Relaxation and Resonance

Effects of Vortex Pinning on the Temperature Dependence of the Magnetic Field Distributions in Superconductors

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Abstract

The temperature and applied-magnetic-field dependence of the second moments of the magnetic-field distributions as measured by μSR for YBCO and BSCCO have been fit for four different intrinsic-field-distribution models (d-wave, 2-fluid, empirical, and BCS). It is found that if a pinning potential becomes important at about 20 K, all of the models can fit the data reasonably well. The fits and the associated fitting parameters are presented.

Keywords: superconductivity, vortices, pinning, muon spin rotation
PACS: 74.25.Ha, 74.72.Gh

1. Introduction

The pinning of vortices in superconductors can lead to either broadening or narrowing of the apparent field distribution as was pointed out by Brandt[1]. The extra degrees of freedom associated with this pinning allow one to obtain good fits for a variety of underlying field distributions. We present here the results of data analysis which includes the effect of pinning.

2. Data Analysis Techniques

Data were taken at TRIUMF on single crystals of $YBa_2Cu_3O_{7-\delta}$ (YBCO) and $Ba_2Sr_2CaCu_2O_8$ (BSCCO). We fit in the time domain using a heterodyning technique and then obtain field distribution second moments, σ^2. For YBCO, we used a London field distribution convoluted with a gaussian distribution and for BSCCO, an asymmetric back-to-back gaussian field distribution. For YBCO we added the London σ_L^2 and the convolution σ_M^2 , and then subtracted the background σ_B^2. For BSCCO the background σ_B^2 was subtracted from back-to-back σ_{bb}^2. For the two-fluid model:

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doi:10.1016/j.phpro.2012.04.083

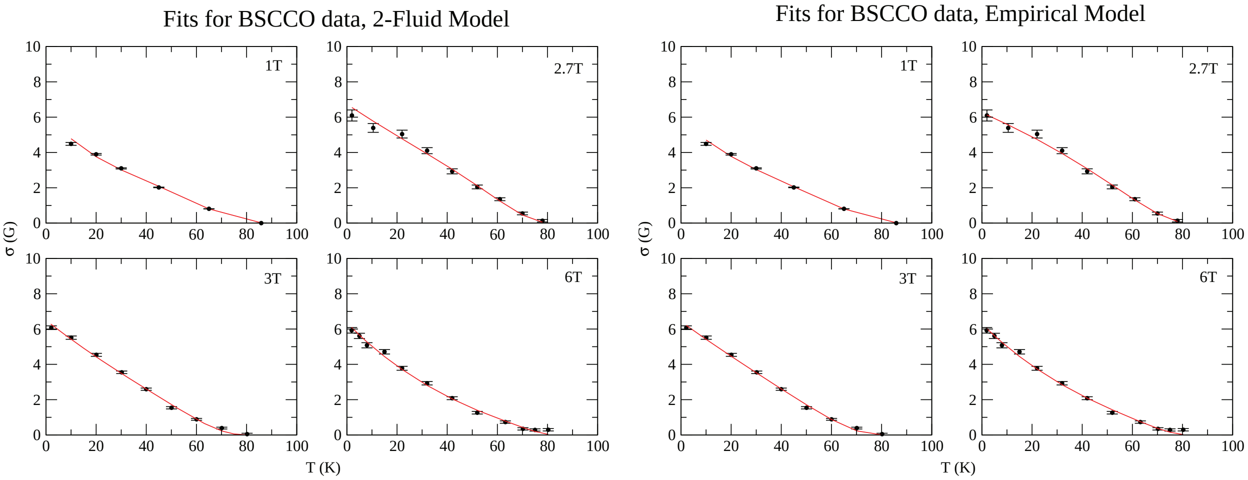

Figure 1: Fits for the 2-Fluid and Empirical Models for BSCCO

$\lambda(0)^2/\lambda(T)^2 = 1 - (T/T_c)^4$, and for the empirical model: $\lambda(0)^2/\lambda(T)^2 = 1 - (T/T_c)^2$. We followed the description in Tinkham's book[2] for the BCS model. For the d-wave we used results of Amin et al.[3] interpolating for our fields. We then fit the temperature dependent σs with disorder following the general procedure of Fiory et al.[4] So:

$$\sigma^2 \approx \sigma_0^2[exp(-26.3u^2/a^2) + 24.8(< u_\ell^2 > /a^2)\ln(\tilde{\kappa})] \qquad (1)$$

The local displacement of a vortex is modeled by $u^2 =< u_\ell^2 > + < u_p^2 >$ and $\tilde{\kappa}^2 = (< u_\ell^2 > +2\lambda_{ab}^2)/(u^2 + 4\xi_{ab}^2)$, where ϵ_0 is an activation energy for vortex depinning from a trap, so that $u_\ell^2 = u_{\ell 0}^2[1 - \exp(-\epsilon_0/T)]$ and is the displacement squared of the vortex line away from its regular lattice position. $< u_p^2 >= u_{p1}^2(H) + (T/T_c)u_{p2}^2(H)$ is the displacement squared of an individual vortex pancake (fluxon) from the mean position of the vortex line, see Brandt[1].

3. Results

In the figures the solid lines are the fitting function. In Table 1 are typical parameters for BSCCO. These should be compared to those for YBCO in Tables 2 and 3. For YBCO the data for all the values of the field were fit at once with the global parameters the same for all fields and the field dependent parameters allowed to change for each field.

Table 1: Parameters for 6T fit for BSCCO. Length measurements are in kÅ, ϵ_0 is in degrees Kelvin

Model	λ_0	T_c (K)	B (T)	ϵ_0	u_{l0}	u_{p1}	u_{p2}	ξ_0	χ^2	χ_N^2
Empirical	2.424	92.0	6	129.183	0.0184	1.465	3.455	0.02	33.112	2.729
2-Fluid	2.992	92.0	6	65.141	0.0333	2.292	3.832	0.02	32.424	2.702
BCS	3.203	92.0	6	121.134	0.0326	1.953	4.879	0.02	33.087	2.757
d-Wave	3.381	92.0	6	108.204	0.0366	2.634	5.208	0.02	29.767	2.481

Table 2: Global parameters for YBCO

$\lambda_0(k\text{Å})$	$\delta\lambda_0$	$T_c(K)$	δT_c	$\epsilon_0(K)$	$\xi_0(k\text{Å})$
1.276	.015	90.8	0.5	19.6	0.02913

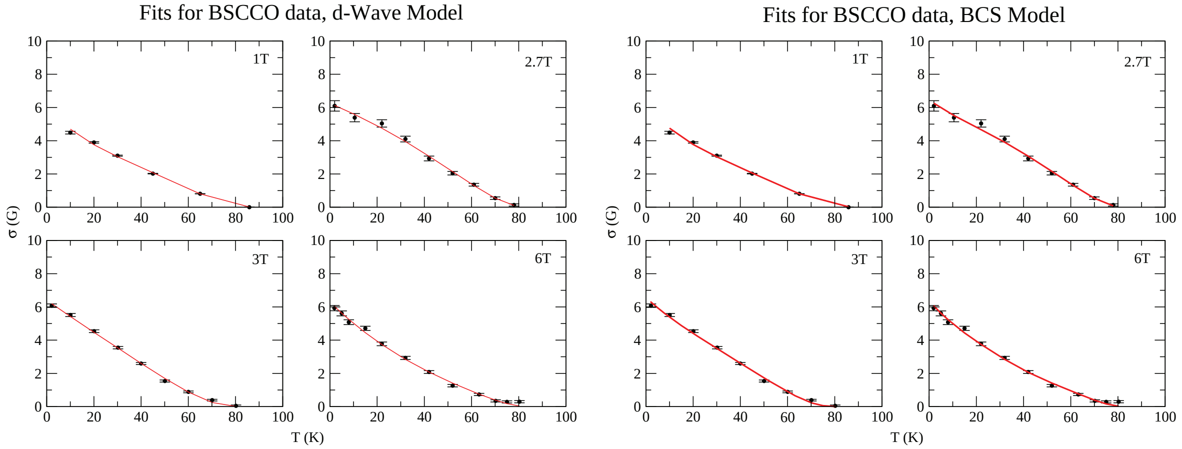

Figure 2: Fits for the d-wave and BCS Models for BSCCO

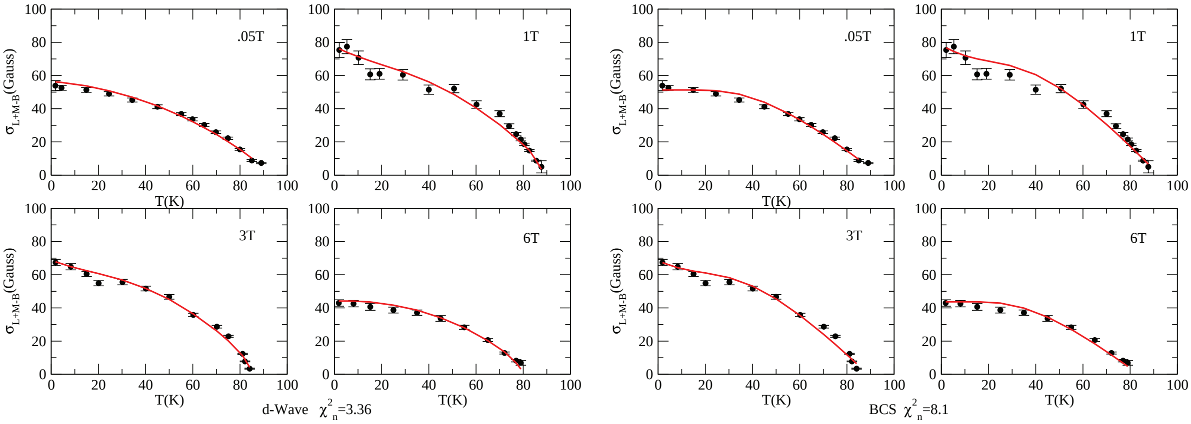

Figure 3: Fits for the d-wave and BCS models for YBCO

4. Conclusions

From the figures one sees the data are reasonably well fit. The BSCCO data require a very large degree of pancake disorder to fit. One could argue that the u_p values here imply that there is hardly any order at all. Further, there is no quality of fit distinction among the models. The YBCO data have indications of a kink around 20 K. This can be reproduced with a trapping-induced increase in the second moment which sets in at about that temperature. For YBCO the best fit is with the 2-fluid model (see the $\chi^2 s$ on the figures). This is due to the flatness of this σ temperature-dependence near T=0 allowing a better fit to the observed kink. This is consistent with the results previously published for YBCO by Harshman et al. [5] and Fiory et al.[4]. However, more complex pinning behavior has not been considered.

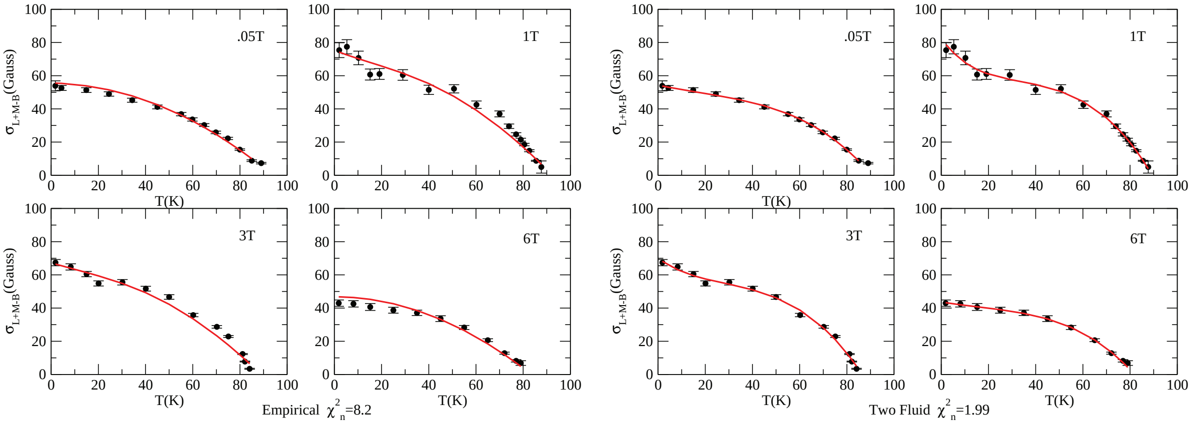

Figure 4: Fits to YBCO with the empirical model and with the two-fluid model.

Table 3: Field-dependent parameters for YBCO using the two-fluid model as an example.

H(T)	$u_\ell(k\AA)$	$< u_p^2 >^{1/2}$ ($k\AA$)	$\delta < u_p^2 >^{1/2}$ ($k\AA$)
0.05	0.0677	0.4559	0.03
1	0.0523	0.06258	0.012
3	0.02484	0.02456	0.0084
6	0.01966	0.02375	0.0064

Acknowledgements

C. E. Stronach was supported in part by the Air Force Office of Scientific Research. W. J. Kossler, M. Shinn, and A. C. Shockley were supported in part by NSF REU grant: 0755262. We would especially like to thank A. T. Fiory, for helpful discussions and David B. Mitzi for providing the BSCCO sample and A. Erb for the YBCO. The experiments were carried out at TRIUMF with the aid of the staff there.

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