VU Research Portal

Hagen and Griessen reply

Griessen, R.; Hagen, C.W.

published in

Physical Review Letters
1990

DOI (link to publisher)

[10.1103/PhysRevLett.65.1284](https://doi.org/10.1103/PhysRevLett.65.1284)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Griessen, R., & Hagen, C. W. (1990). Hagen and Griessen reply. *Physical Review Letters*, 65(10), 1284-1284.
<https://doi.org/10.1103/PhysRevLett.65.1284>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:

vuresearchportal.ub@vu.nl

Hagen and Griessen Reply: Although Chaddah and Bhagwat¹ point out rightly in their Comment that the relaxation rate of the magnetization M of a superconductor depends on the field profile inside the sample at time $t=0$, we show here that their argument is based on a wrong expression for $M=M(t)$.

In several publications²⁻⁴ we have shown, on the basis of Monte Carlo simulations as well as of an exact solution of a four-pinning-region model, that over approximately 90% of the relaxation

$$M(t) = M(t=0) \left[1 - \frac{kT}{E(T)} \ln \left(1 + \frac{t}{\tau} \right) \right], \quad (1)$$

if (i) the sample is homogeneous, in the sense that all pinning centers are described by the same activation energy $E(T)$, and (ii) the field has initially completely penetrated the sample so as to establish a critical state. These two conditions guarantee that everywhere the current density j is equal to the critical current j_c at $t=0$. For $t \gg \tau$ (as is the case in all experiments carried out so far) Eq. (1) reduces to Eq. (1) in the Comment.

In Eq. (3), Chaddah and Bhagwat¹ assume without derivation that the same logarithmic time dependence is valid for the case where the field has not penetrated the sample completely at $t=0$, i.e., when $H < H^*$. We show here that this assumption which has also been made by many other authors (see, e.g., Refs. 5-9) is, in fact, not justified.

FIG. 1. Magnetization relaxation normalized to its value at $t=0$ for a sample containing twenty pinning centers as obtained from Monte Carlo simulations. For the fully field-penetrated sample *a*, the density of flux lines at $t=0$ decreases from 1300 at the surfaces of the slab to 400 at the center of the sample. For sample *b*, the density of flux lines decreases from 900 at the surfaces to zero at the center. This corresponds to $H=H^*$. For the partially penetrated samples *c* and *d*, the density is 500 and 100, respectively, at the surface. The density gradient (i.e., the critical current) and $E/kT=7.5$ is the same for all samples. The time is indicated in units of Monte Carlo (MC) steps.

For this we consider a slab of thickness $2a$ and infinite dimensions in the y and z directions in a magnetic field H applied along the z axis. At $t=0$, $|j|=j_c$ in a surface sheet $x_0 < |x| < a$, and $j=0$ in the central part, $|x| \leq x_0$, of the sample. Using the same Monte Carlo simulation as in Refs. 3 and 10 we obtain the relaxation curves shown in Fig. 1 for various cases of fully and partially field-penetrated samples. For the partially penetrated samples, $M(t)$ does not obviously vary linearly with $\ln t$ and the relaxation rate $dM/d \ln t$ is not uniquely defined; i.e., $A(H)$ in Eq. (3) of Chaddah and Bhagwat is, in fact, strongly *time dependent*. An analytic expression for $A(H, T, t)$ will be published elsewhere.¹⁰ It is important to point out that convex M vs $\ln t$ curves in partially penetrated $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_x$ single crystals have been observed by Shi, Xu, and Umezawa⁸ (e.g., at 8 K in a field of 0.1 T).

In conclusion, we do not believe that a maximum in $d \ln M / d \ln t$ can satisfactorily be explained with the arguments put forward by the authors. It is, however, obvious that relaxation processes in partially field-penetrated samples have to be taken into account for a correct description of flux creep at low fields and temperatures.

C. W. Hagen

Paul Scherrer Institut
Forschungsbereich F3
CH-5232 Villigen, Switzerland

R. Griessen

Department of Physics and Astronomy
Free University
1081 HV Amsterdam, The Netherlands

Received 24 April 1990

PACS numbers: 74.60.Ge, 74.70.Vy

¹P. Chaddah and K. V. Bhagwat, preceding Comment, Phys. Rev. Lett. **65**, 1283 (1990).

²C. W. Hagen and R. Griessen, in *Studies of High Temperature Superconductors*, edited by A. V. Narlikar (Nova, Comack, NY, 1989), Vol. 3, p. 159.

³C. W. Hagen, R. Griessen, and E. Salomons, Physica (Amsterdam) **157C**, 199 (1989).

⁴C. W. Hagen and R. Griessen, Phys. Rev. Lett. **62**, 2857 (1989).

⁵Y. Yeshurun, A. P. Malozemoff, T. K. Worthington, R. M. Yandofski, L. Krusin-Elbaum, F. H. Holtzberg, T. R. Dinger, and G. V. Chandrasekhar, Cryogenics **29**, 258 (1989), see Eq. (1).

⁶P. Chaddah and G. Ravikumar, Physica (Amsterdam) **162-164C**, 347 (1989), and references therein.

⁷P. H. Kes, J. Aarts, J. van den Berg, C. J. van der Beek, and J. A. Mydosh, Supercond. Sci. Technol. **1**, 242 (1989).

⁸Donglu Shi, Ming Xu, and A. Umezawa (to be published).

⁹B. D. Biggs, M. N. Kunchur, J. J. Lin, S. J. Poon, T. R. Askew, R. B. Flippen, M. A. Subramanian, J. Gopalakrishnan, and A. W. Sleight, Phys. Rev. B **39**, 7309 (1989).

¹⁰R. Griessen, J. G. Lensink, T. A. M. Schröder, and B. Dam, Cryogenics (to be published).