Comment on "Self-Heating versus Quantum Creep in Bulk Superconductors"

In their recent Letter Gerber and Franse [1] argue that in bulk high-T_c superconductors the nonvanishing magnetization relaxation at low temperatures is not due to quantum tunneling but to self-heating effects. In a nice experiment they confirm the well-known fact that the dissipation associated with the movement of vortices leads *under adiabatic conditions* to a rise of the temperature of the sample. Contrary [2] to their Eq. (1), the dissipated power P is given by the integral over the sample volume of $\mathbf{j}\cdot\mathbf{E}$ where $\mathbf{j}$ is the current density and $\mathbf{E}=\mathbf{B}\times\mathbf{v}$ (where $\mathbf{v}$ is the velocity of the vortices and $\mathbf{B}$ the local magnetic induction). For a disk shaped sample of radius R and thickness D the magnetic moment is $M\cong jR^3D$ and during creep $P\cong t^{-1}\mu_0 j^2R^3D^2(d\ln M/d\ln t)$ where the time t is measured from the start of the relaxation. The relaxation rate is typically $d\ln M/d\ln t=10^{-2}$. For $R=1.3\times10^{-3}$ m, $D=10^{-4}$ m and $j=5\times10^9$ A/m^2 which is typical for BiSrCaCuO at 1 T and low temperatures we obtain at $t=5000$ s, $P\cong1.4$ nW, and $dP/dt\cong-0.3$ pW/s, of the same order of magnitude as in [1].

The authors calculate the temperature profile inside the sample in the case of a phonon dominated thermal conductivity $k=\alpha T^3$ with $\alpha=0.25$ W/m K^4 and conclude from their Eq. (3) that T_i, the temperature in the center of the sample, can be drastically larger than its surface temperature T_s. For example, for a cubic sample with side $l=5\times10^{-4}$ m and a power dissipation $P=1.5$ nW they find $T_i=0.112$ and 12.01 K for $T_s=0.1$ and 0.01 K, respectively. They conclude, therefore, that low-temperature relaxation is due to an internal self-heating effect.

In this Comment we show that there are three strong reasons to believe that the conclusions of Gerber and Franse are wrong.

(1) From their analysis (and *a fortiori* from the correct analysis given below) thin films should not suffer from significant self-heating effects. Hence, if self-heating were important one would observe in thin films a different behavior from single crystals, in contradiction with existing data for $YBa_2Cu_3O_7$ where $d\ln M/d\ln t$ at low temperatures is of the same order of magnitude for films and bulk single crystals [3].

(2) Equation (3) in Gerber and Franse's paper is not the correct solution for a cubic sample of side l with a heat source of power P on one of the faces. Treating the heat conduction in a one-dimensional approximation they calculate the temperature T_i of the face where P is pumped into the sample as a function of the bath temperature T_s of the opposite face. In a stationary state the same power P is transferred through any cross-sectional area l^2 of the sample, i.e., $P=kl^2(dT/dx)$. With $k=\alpha T^3$ one obtains after integration that

$$T_i=(T_s^4+4P/\alpha l)^{1/4}, \tag{1}$$

which reduces to $T_i=(T_s^4+4.8\times10^{-5})^{1/4}$ for $P=1.5$ nW and $l=5\times10^{-4}$ m. At all $T<10$ mK this leads to $T_i\cong83$ mK, instead of $T_i>12.01$ K found by Gerber and Franse by using their Eq. (3).

(3) For both $YBa_2Cu_3O_7$ films and single crystals M exhibits logarithmic time decay and $d\ln M/d\ln t$ remains essentially constant over many decades in time. Below a certain temperature T^* (typically $T^*=1$ K) $d\ln M/d\ln t$ is experimentally found to remain constant [3–5]. In the absence of quantum tunneling and for the measured dissipation one would expect (since in that case $d\ln M/d\ln t\propto T$) a plateau below 83 mK [see point (2)] instead of 1 K as observed experimentally. In order to have $T_i=T^*\cong1$ K one would need a power dissipation which is more than 2×10^4 times larger, i.e., ≈31 μW.

In conclusion, self-heating by moving vortices is certainly *not* an essential obstacle for the observation of macroscopic quantum creep in bulk superconductors (by bulk we mean samples of typically $1\times1\times0.1$ mm^3). It can easily be avoided by using films in good contact with the thermal bath. The second term in Eq. (1) is then proportional to D/R^2 (D is the film thickness, R its radius) instead of $1/l$ and hence is reduced by many orders of magnitude.

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[2] Note that both relations in Eq. (1) of Ref. [1] are incorrect. During creep dissipation does not depend on the external applied magnetic field and dB/dt is not equal to the electric field.
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