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RELAXATION OF THE MAGNETIC MOMENT OF $Bi_2CaSr_2Cu_2O_{8+x}$ SINGLE CRYSTALS IN THE MILLISECOND REGION

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ANNOTATION

The relaxation of the magnetic moment of $Bi_2CaSr_2Cu_2O_{8+x}$ single crystals in the millisecond region has been investigated with the use of an impulse magnetic field of trapezoidal form. It has been established that the time dependence of the magnetic moment in the field was logarithmic in the range 0.2–2.0 msec and the temperature interval 8–25K. The comparative analysis of data with the use of the Anderson-Kim model and the theory of collective creep shows that the experiment may be properly explained from the notion of the collective character of the creep.

The magnetic properties of superconductors of type II in the mixed state are defined by the vortex lines structure, their interaction with each other, and with defects in the sample. The small value of the characteristic energies of the vortex structure for high-T_c superconductors (HTS) is the consequence of the small coherence length, and therefore the influence of thermodynamic fluctuations becomes more significant. It will result in quite unusual events, including rapid magnetization decay of HTS. However, the present data on the relaxation of the magnetic moment on single crystals, obtained as a rule with the use of SQUID, usually include the observation time intervals beginning from $t > 1$ sec[1–2].

It is very interesting to spread this research over the region of the smallest times. In the work [4] investigating a textured YBaCuO sample, the impulse magnetic field of the amplitude up to 1 T and duration from 10^{-4} to 10^{-2} sec is used for these purposes. The authors of this work studied the relaxation of the residual moment after the influence of the impulse of the magnetic field, i.e., the relaxation in the zero external field was investigated. In this case, one may consider that the process of relaxation is occurring in the magnetic field, being created by the currents flowing in the sample. As the field value changes in time, then it complicates the interpretation of the results obtained in this case. It is more correct, in this sense, to study the relaxation in the constant magnetic field[8,11] using an impulse magnetic field of trapezoidal form.

An experimental setup used for this experiment is analogous to that used for the determination of the critical current density by the modulation method[5]. The low-temperature device part included the modulation, primary, and compensation (pickup) coils, with a small glass cryostat installed inside the primary and compensation coils. A sample was fastened on the sapphire rod, above which the thermocouple and a heater were located. This system, located in the cryostat, allows one to smoothly change the sample temperature with the speed of about 1–2 K/min in the range 4.2–250 K. The precision of the temperature determination was ≤ 0.05 K. The impulse magnetic field of trapezoidal form, with the front of the field increase about 1 msec, the amplitude up to 40 mT, and duration 1–10 msec, was created with the help of a current impulse generator. The deviation of the field shape from trapezoidal did not exceed 1%. The signal from the couple of pickup coils, switched on in opposite directions to each other, was received through the wide-band differential amplifier at the first input of the digital memory oscillograph. The time constant of the channel for the signal transfer was less than 0.05 msec. The field form was controlled on the current flowing through the modulation coil. This signal was received at the second input of the oscillograph. During the experiment the coils were at liquid-helium temperature. The primary and compensation coils were manufactured in such a way that the degree of identity precision was $\leq 0.1\%$. The additional compensating elements were not used, in order to avoid distortions in the investigated signal. The small signal, connected with the incomplete identity of coils, was determined from measurements at the temperature exceeding the T_c of the samples, and was further taken into consideration while processing the results.

The investigated $Bi_2CaSr_2Cu_2O_{8+x}$ single crystals[6], with $T_c = 80$ K, had the form of thin plates with dimensions along the ab plane of about 1 mm and thickness of about 5 μm. In these experiments, the samples were located in such a way that the magnetic field was perpendicular to the ab plane.

The records of the response from the pickup coils under the influence of the impulse magnetic field at various temperatures are given in Fig. 1. The field amplitude equals 30.5 mT, which exceeds the H_{c1} of the samples. At high temperatures, the signal from the sample is very small. The signal becomes well observable at temperatures lower than 35K. One should pay attention to the region where the field is constant. The signal appearance at this region is evidence that although the magnitude of the magnetic field is not changed at this time period, the magnetization decays, i.e., the vortex lines continue to move.

It may be suggested that this response is due to the weak pinning, and the vortex movement is decelerated only by the viscous friction. The factor of the viscous friction η is introduced phenomenologically in such a way that the density of the viscous force per unit of length of the moving vortex with a speed v equals $-\eta v$[10]. This is the so called flux flow regime that results in flux flow resistivity ρ_f. In this case, exponential decay of the magnetic moment in time may be expected. However, the resultant data show that this is not the case.

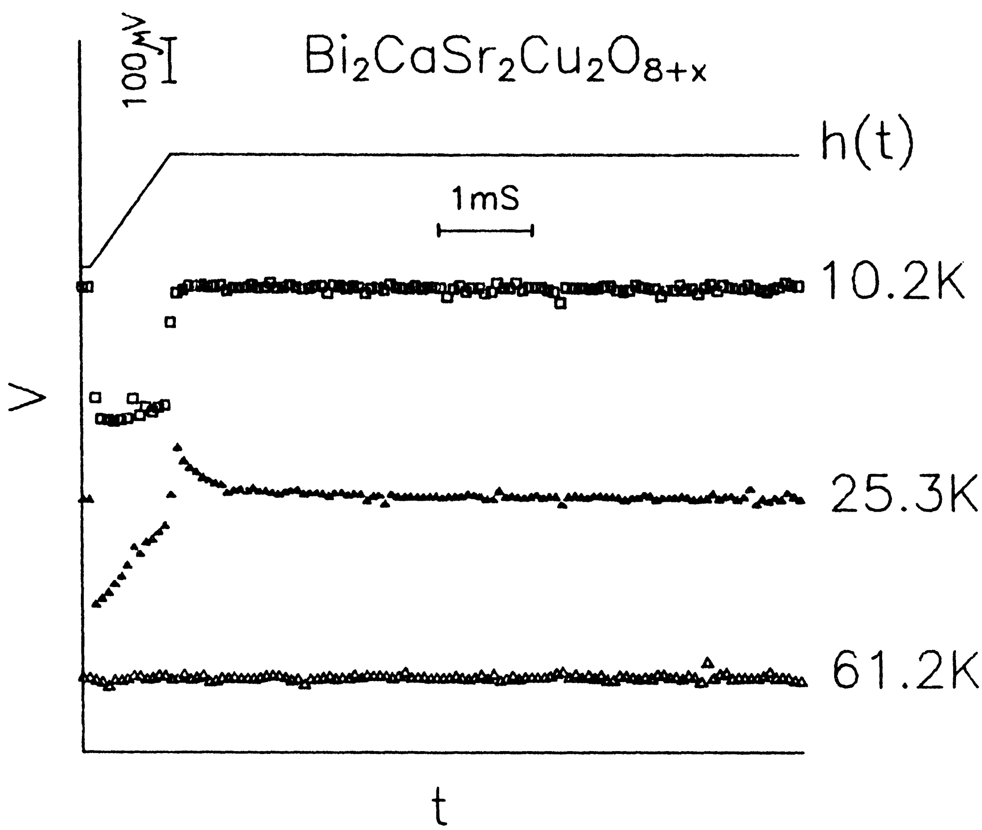

FIGURE 1 Oscillograms taken at various temperatures.

The experimental data points for two temperatures at the coordinates $-(t^2/M_0)(dM/dt)$ and t are plotted in Fig. 2. The zero time point corresponds to that moment of time when the field becomes constant, which corresponds to the beginning of the trapezium plato. M_0 is the magnitude of the magnetic moment gain by the sample for the period of the field increase. The experimental points lie on a straight line in the chosen coordinates. This means that the moment derivative with respect to time is inversely proportional to the time, and consequently, the magnetic moment depends on time logarithmically.

The simple logarithmic dependence may be explained proceeding from the Anderson-Kim model of thermoactivated creep[7]. This model predicts the following time dependence:

$$M(t) = M_0 \left(1 - \frac{T}{U_0} \ln \frac{t}{t_0}\right) \tag{1}$$

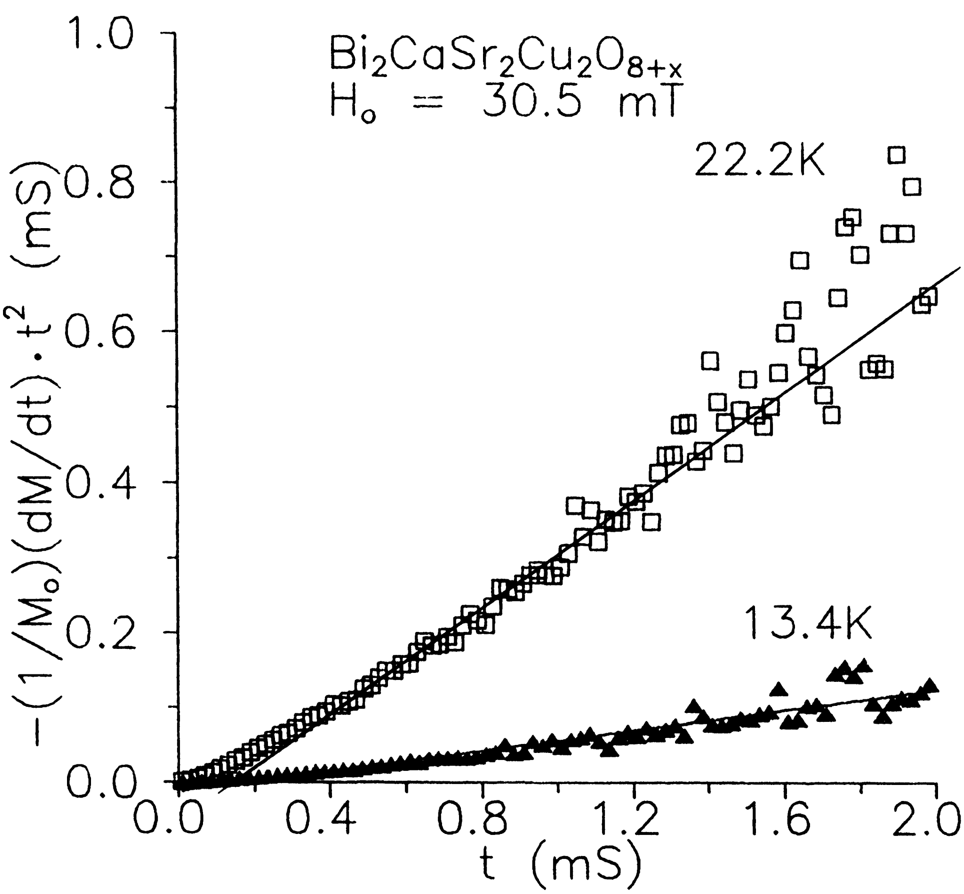

FIGURE 2 Experimental data on magnetic moment relaxation.

where U_0 is the typical value of the pinning potential of the flux lattice, T is temperature, and t_0 is a some characteristic time, which is considered to be comparable to the microscopic time $t_{mic} = 10^{-12}$ sec.

However, we will further show that a more consistent picture may be obtained with the use of the collective creep theory[3], which predicts a more complex dependence of the magnetic moment relaxation on time:

$$M(t) = M_0\left(1 + \alpha\frac{T}{U_0}\ln\frac{t}{\tau_0}\right)^{-1/\alpha} \quad (2)$$

where α is a magnitude of the order of unity, and depends on the pinning regime[3]. The experimentally obtained value for $\tau_0 \sim 10^{-4}$ sec^2. In the work[8] it was shown that τ_0 must not necessarily be microscopically small.

We consider that time τ_0 may not be small, for the following simple reasons. Let us take for the typical dimensions of single crystals l = 1 mm, thickness d =

1 μm. At the moment of completion of the external excitation associated with the magnetic field change in the sample, the current densities close to the critical value and possibly exceeding it are excited. In this case $\rho \sim \rho_f$ may be taken for the magnitude of the resistivity of the sample, where ρ_f is the flux flow resistivity. Taking the above into consideration, with $\rho = 1$ μOhm · cm, the inductance L of the sample will be about 1 μH, resistance R ~ 0.01 Ohm, and the magnitude $\tau = L/R \approx 10^{-4}$ sec. The exponential decay will transform into long-term relaxation, given that the resistance R tends to zero with reduction in the current I. The latter may be related, for example, with the realization of the "vortex glass" phase[9].

Thus, by taking $\tau_0 \sim 10^{-4}$ sec, we obtain that the second term in brackets in expression (2) for the time region t ~ 10^{-3} sec is small with respect to unity. Using

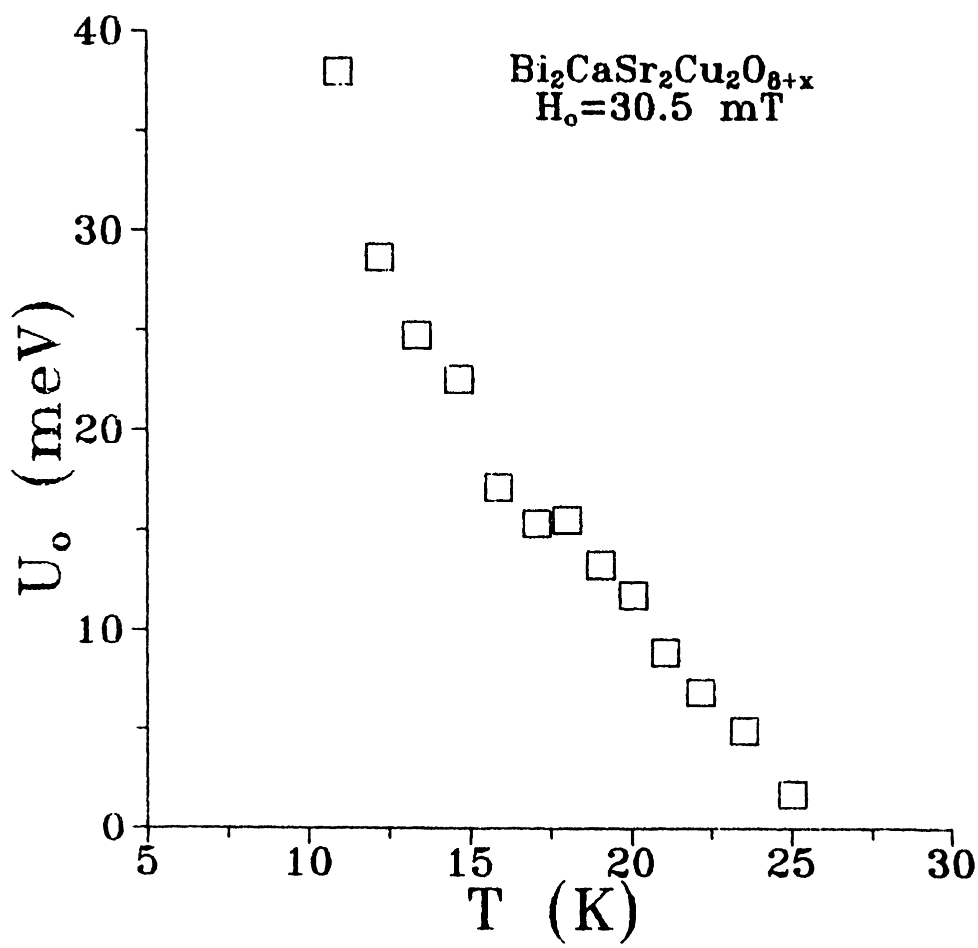

FIGURE 3 Temperature dependence of the pinning potential magnitude figuring in the theory of collective creep.

Taylor's expansion, expression (2) can be transformed to:

$$-\frac{1}{M_0}\frac{dM}{dt} = \frac{T}{U_0}\frac{1}{t} \tag{3}$$

Fig. 3 shows the temperature dependence of the pinning potential U_0, determined from the slope of the lines in Fig. 2. The characteristic pinning energy value is about 10 meV and increases with a reduction in temperature.

Expression (3) may also be derived from the Anderson-Kim model. However, the small pinning potential values derived do not allow explanation of the long-term relaxation, because in accordance with the concept of thermoactivated creep, the magnetic moment relaxes almost to zero over the characteristic time $t_{cr} \propto t_{mic} \exp(U_0/T)$. If one puts $U_0 \approx 10$ meV, $T = 20K$, then t_{cr} will be of the order of 10^{-9} sec.

Another evidence in favor of the fact that the theory of collective creep enables more adequate description of the experimental data comes from the research[2] for observation times $t > 1$ sec, carried out on single crystals of $Bi_2CaSr_2Cu_2O_{8+x}$. This data shows that relaxation over time deviates from a simple logarithmic law (1), and the data are best described by expression (2).

Thus, in the given work, it is established that in the time interval 0.2–2.0 msec and the temperature interval 8–25K, the magnetic moment of the single crystals of $Bi_2CaSr_2Cu_2O_{8+x}$ in the field decays not exponentially, but logarithmically in time. The revealed type of dependence proposes that the observed behavior is conditioned by the thermoactivated flux creep. From comparative analysis of the data with the use of the Anderson-Kim model and the theory of collective creep, it is shown that the experiment may be explained more consistently by proceeding from conceptions of the collective character of the creep.

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