Muon spin relaxation in crystalline and amorphous states of $Cu_{10}Zr_7$

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(Submitted 10 July 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **42**, No. 5, 195–197 (10 September 1985)

A muon method can be used to study amorphous metals. A study of the alloy $Cu_{10}Zr_7$ by a muon method shows that the short-range order is approximately the same as in the amorphous and crystalline states of this alloy.

Comparison of the spin relaxation of a positive muon in the crystalline and amorphous states of a metal can yield important information on the atomic structure of the amorphous state. The relaxation rate (Λ) found experimentally in a nonmagnetic metal is determined by the dipole interactions of the magnetic moments of the muon and of the surrounding nuclei. The rate Λ essentially depends on only the metal atoms nearest the muon, since for dipole interactions we have $\Lambda \sim 1/R^3$, where R is the distance between the muon and the nucleus with which it is interacting. Accordingly, measurements of Λ in the crystalline and amorphous states of the metal of interest can reveal information on a difference between the arrangement of nearest atoms in those interstitial positions where the muon localizes in these states. The muon method is an important supplement to other methods for studying the short-range structure of the amorphous state, such as neutron and x-ray diffraction. The magnetic fields found at a localized muon and at a diffusing muon by the muon method provide much information on the amorphous state of a metal.

In the present study we used a muon method to study the amorphous state of the alloy $Cu_{10}Zr_7$. In its crystalline state this alloy is a phase which, like the CuZr and $CuZr_2$ phases, can be quenched into an amorphous state. Several properties of the amorphous state of a copper-zirconium alloy were studied in Refs. 1–4.

The crystalline $Cu_{10}Zr_7$ sample is prepared by electric-arc smelting in argon. The total impurity concentration in the initial metals is $\sim 10^{-2}$ at.%. An amorphous tape of $Cu_{10}Zr_7$ ~ 5 mm wide and $\sim 20\,\mu$m thick is synthesized by quenching the melt on a rotating copper cylinder in helium.

A check was made by x-ray diffraction to ensure that the metal produced by this method was amorphous. The samples are disks ~ 5 mm thick and 60 mm in diameter. The amorphous sample is prepared from the tape in the form of a tightly coiled spiral with a total weight of 300 g. The direction of the external magnetic field ($B = 100$ Oe) is parallel to the plane of the disk and perpendicular to the muon polarization. The experiments are carried out in the polarized muon beam of the synchrocyclotron of the Leningrad Institute of Nuclear Physics at Gatchina.

The relaxation rate Λ in the crystalline and amorphous states of the $Cu_{10}Zr_7$ is measured under the assumption that the muon polarization is a Gaussian function of the time: $P(t) = e^{-\Lambda^2 t^2}$. Figure 1 shows the temperature dependence $\Lambda(T)$ found by this approach. We see that, within the experimental errors, the values of Λ for the crystalline and amorphous states of $Cu_{10}Zr_7$ agree over the entire temperature interval studied. The decrease in Λ with increasing temperature observed for the crystalline and amorphous states is a consequence of an increase in the muon diffusion rate with increasing temperature.

The agreement between the values of Λ over a broad temperature range means that the nuclear magnetic fields at the muon, i.e., at interstitial positions, are identical in the crystalline and amorphous states. The muon diffusion rates are also identical.

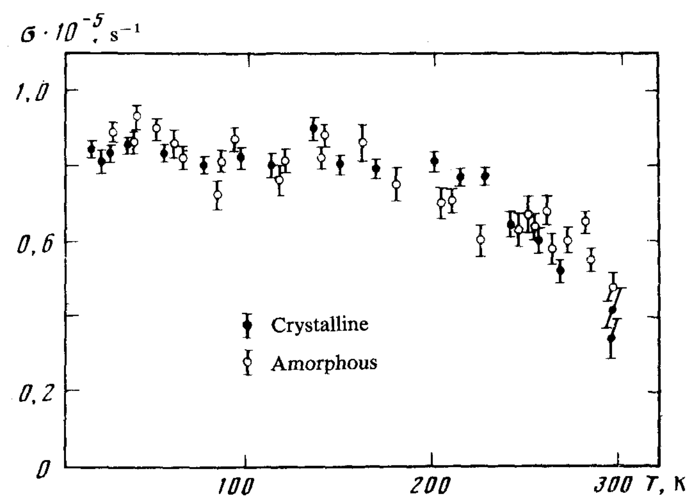

FIG. 1. Temperature dependence $\Lambda(T)$ of the relaxation rate of the muon spin in the crystalline and amorphous states of $Cu_{10}Zr_7$.

These results can be explained in a natural way by assuming that the amorphous $Cu_{10}Zr_7$ consists of clusters whose atomic structure differs only slightly from that of the crystalline state. The size of a cluster presumably does not exceed a few crystal cells. A muon diffusing in such a cluster does not escape from the cluster over the observed time, and the value of Λ characterizing its diffusion remains the same as in a crystalline sample.

It should be kept in mind, however, that the crystal structure of the alloy $Cu_{10}Zr_7$ is complex: The unit cell contains 68 atoms and many interstitial positions of various symmetries. It may happen by chance that the values of Λ for localized and diffusing muons in this crystal are approximately the same as those in the amorphous state with a random distribution of atoms. In order to obtain more-detailed information on the short-range structure of the amorphous state of $Cu_{10}Zr_7$, we need to measure the values of Λ more accurately for the crystalline and amorphous states and to compare these values over a temperature range as broad as possible.

At any rate, the agreement between the values of Λ for the crystalline and amorphous states of $Cu_{10}Zr_7$, which is illustrated in Fig. 1, shows that the short-range structure is approximately the same in these two states. Of interest in this connection is Garoche and Bigot's study,[4] where it was found that the specific heats of the crystalline and amorphous alloys $Cu_{10}Zr_7$ agree in the temperature interval $T = 0.3$–10 K, while they are sharply different for five copper-zirconium alloys of other compositions.

We wish to thank O. I. Sumbaev and A. A. Vorob'ev for cooperation in, and support of, this study; M. T. Berezov, A. F. Burtsev, A. N. Zaikaev, Yu. A. Skakov, V. G. Ol'shevskiĭ, and V. N. Dushnov for assistance in this study; and V. G. Vaks for useful discussions.

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Translated by Dave Parsons