Observation of antiferromagnetic transitions by the μ^+ meson method

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(Submitted February 16, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 6, 345–348 (20 March 1976)

The phase transition from the paramagnetic to the antiferromagnetic state in dysprosium and holmium is investigated by the method of observing μ^+-meson precession in a transverse magnetic field at temperatures $T = 100$–300°K. The abrupt change in the amplitude and in the rate of damping of the μ^+-meson precession at the Néel temperature T_N demonstrates the effectiveness of the μ^+-meson method of investigating the antiferromagnetic transition.

PACS numbers: 75.30.Qe

The antiferromagnetic transition at the Néel temperature T_N in dysprosium (Dy) and holmium (Ho) was investigated by observing the μ^+-meson spin precession in a transverse magnetic field. We investigated polycrystalline samples of Dy and Ho with less than 0.2% impurity. The samples were disks of 80 mm diameter and 10 mm thick.

The experimental setup for the observation of μ^+-meson precession in Dy and Ho are shown schematically in Fig. 1. The longitudinally-polarized μ^+ mesons were decelerated and stopped in a target T of the investigated substance. The target T was placed in a magnetic field $H = 306$ Oe transverse to the direction of the μ^+-meson spin. The instant t_μ of the stopping of the μ^+ mesons was fixed by a $123\bar{4}$ system of scintillation-counter signals (coincidence of the signals 1, 2, and 3 and anticoincidence of the signal 4). The instant t_e of the emission of the positron of the $\mu^+ \to e^+$ decay was registered by signals $456\bar{3}$. The work was performed with the JINR synchrocyclotron in Dubna.

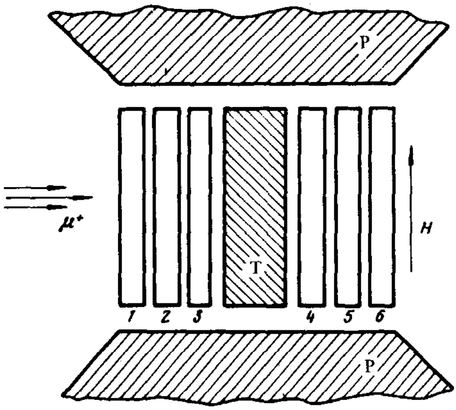

FIG. 1. Experimental setup: T) Dy or Ho target, P) electromagnet pole pieces, 1)—6) scintillation counters.

The μ^+-meson spin precession, i.e., the dependence of the count $N(t)$ of the

$456\overline{3}$ positron telescope on the time $t = t_e - t_\mu$, was observed in standard fashion and is well approximated by the expression

$$N(t) = e^{-t/\tau_0}(1 - a e^{-\lambda T} \cos \omega t) N_0 .$$

In the entire temperature interval $T = 100$—300 °K. Here $\tau_0 = 2.2 \times 10^{-6}$ sec is the lifetime of the μ^+ meson; $\omega = eH/mc$ is the frequency of the Larmor precession of the spin of the μ^+ meson in an external field $H = 306$ Oe; m is the mass of the μ^+ meson; a is the experimental symmetry coefficient of the angular distribution of the positrons of the $\mu^+ \to e^+$ decay; λ is the μ^+-meson spin relaxation rate. The asymmetry coefficient a determines the initial polarization $p = a/a_{\text{Cu}}$ of the μ^+ meson, where a_{Cu} is the asymmetry coefficient in a non-depolarizing substance, in this case copper.

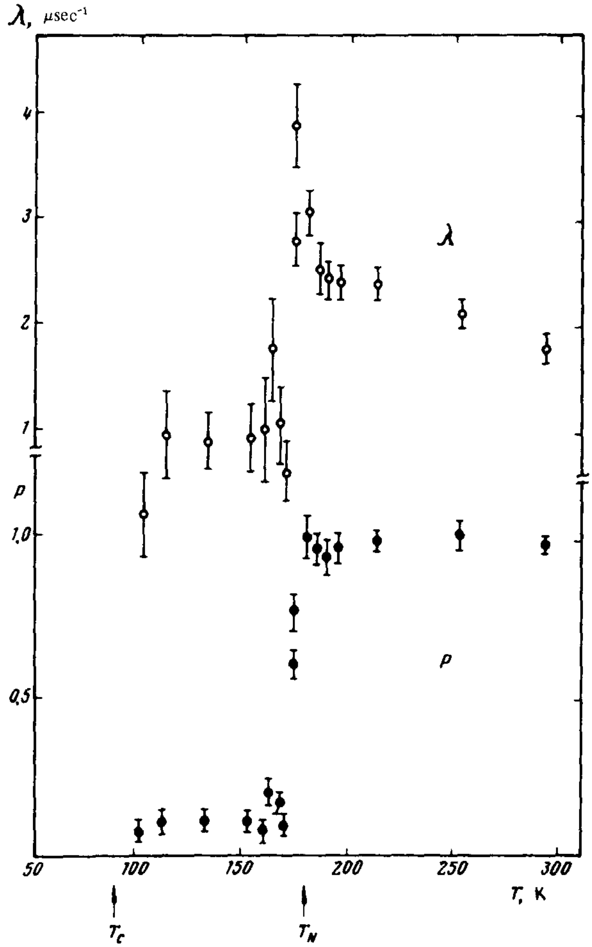

FIG. 2. Polarization p and relaxation rate λ of the spin of the μ^+ meson in Dy as a function of the temperature T, $T_N = 179$ °K is the Néel temperature, $T_C = 90$ °K is the Curie temperature of the transition into the ferromagnetic state.

Figs. 2 and 3 show the temperature dependence of $p(T)$ and $\lambda(T)$, which characterize the precession of the μ^+ meson in Dy and Ho at $T = 100 - 300$ °K. It is seen from these figures that Dy and Ho have similar plots of $p(T)$ and $\lambda(T)$. At the temperature T_N of the phase transition from the paramagnetic state $(T > T_N)$ to the antiferromagnetic state $(T < T_N)$, both the polarization p and the relaxation rate λ undergo abrupt changes.

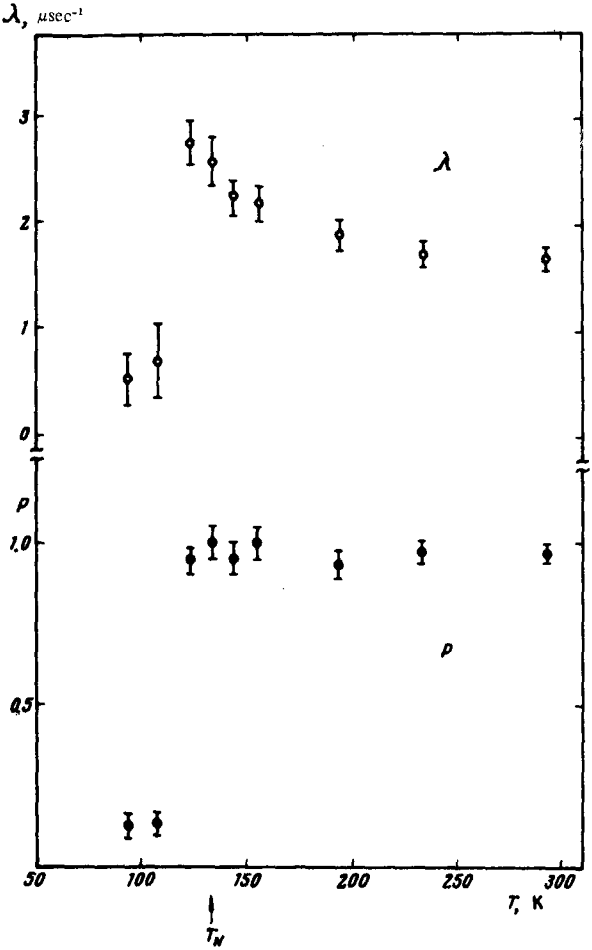

FIG. 3. Polarization p and relaxation rate λ of the spin of the μ^+-meson in Ho as a function of the temperature T, $T_N = 133$ °K is the Néel temperature.

The initial polarization p at $T < T_N$ decreases almost to zero; the observed precession of the μ^+ meson in Dy and Ho at these temperatures corresponds to the value $p \approx 10\%$. The small value of p at $T < T_N$ corresponds to a rapid depolarization, which cannot be observed in this experiment, of approximately 90% of all the Dy and Ho, μ^+ mesons that are in the antiferromagnetic state.

There remains, however, a small number ($\lesssim 10\%$) of μ^+ mesons, the spins of which relax slowly at $T < T_N$ ($\lambda \sim 1\ \mu\text{sec}^{-1}$).

The relatively high relaxation rate $\lambda \sim 2\ \mu\text{sec}^{-1}$ of the μ^+-meson spin in Dy and Ho at $T > T_N$ is the consequence of the large local magnetic fields produced by the magnetic moments of the atoms of these metals in the paramagnetic state. Calculation shows that the values of λ would be even larger if the μ^+ meson were not to diffuse over the Dy and Ho crystal. When the μ^+ meson diffuses, the local magnetic fields at the meson become alternating in time and the relaxation rate of the μ^+-meson spin decreases. The increase of the diffusion rate can also explain the experimentally observed decrease of λ with increasing temperature in the region $T > T_N$. Notice should also be taken of the rapid increase of the relaxation rate λ, and consequently of the local magnetic fields, at $T \approx T_N$, as is natural near a phase transition point.

The experimental results demonstrate the effectiveness of using the μ^+-meson method for the investigation of an antiferromagnetic phase transition.

The authors thank V. P. Dzhelepov for the opportunity of performing this work with the JINR synchrocyclotron.