INVESTIGATION OF MAGNETIC PHASE TRANSITION IN $Y_3Fe_5O_{12}$

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We present here the results of an investigation of static and dynamic phenomena in an yttrium iron garnet near the Curie point. We performed experiments with polarized neutrons as well as RF susceptibility measurements.

Experiments with polarized neutrons give sufficiently complete information concerning the fluctuations in a magnetic system near the Curie point T_c [1, 2]. The absence of conductivity in ferrodielectrics makes it possible to carry out RF measurements of the susceptibility [3]. These measurements, as will be shown below, are exceedingly useful not only for the study of the static properties in the critical region (determination of the Curie point and of the critical index of the static susceptibility), but also lead to important conclusions concerning the dynamic phenomena in the critical region.

For a reliable comparison of the results of neutron and RF measurements it is necessary to ensure identical measurement conditions, and the measurements themselves must be performed on the same sample.

Our measurements were made on a $Y_3Fe_5O_{12}$ single crystal in the form of a cylinder 5 mm in diameter and 21 mm long placed in a magnetic screen. The cylinder axis was the [111] axis. The magnetic field in the screen was less than 0.1 Oe, and the high-frequency field applied to the sample was less than one millioersted.

To measure the susceptibility, a measurement coil of 70 turns of copper wire having a diameter 0.2 mm was wound around the sample. The sample together with the measuring coil was placed in a thermostat in which the temperature was maintained constant within 0.005°C.

The neutron measurements were made with a setup described earlier [1]. A polarized-neutron beam of 4 mm diameter passed along the axis of the cylinder. The polarization of the neutrons passing through the sample was determined as a function of the sample temperature. Under the same conditions, we measured the susceptibility of the sample at different frequencies, by connecting the coil, with the sample in it, to an oscillating circuit. A change in temperature produced a change in the coil inductance and in the magnetic losses in the sample. The coil inductance at the given frequency was determined from the value of the capacitance at resonance, and the magnetic losses were determined from

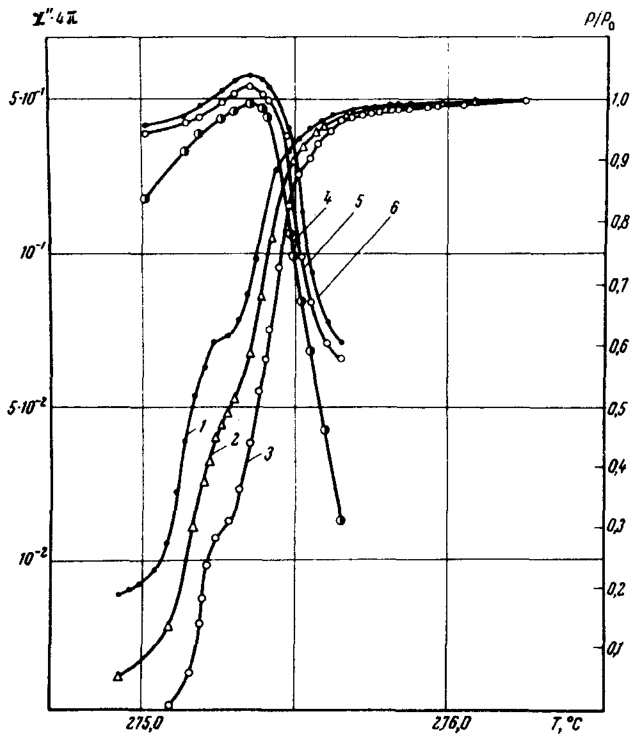

Fig. 1. Temperature dependence of the depolarization of neutrons passing through the sample (1 - λ = 3 Å, 2 - λ = 4 Å, 3 - λ = 6 Å), and of the magnetic losses in the sample (4 - 600 kHz, 5 - 1000 kHz, 6 - 1400 kHz).

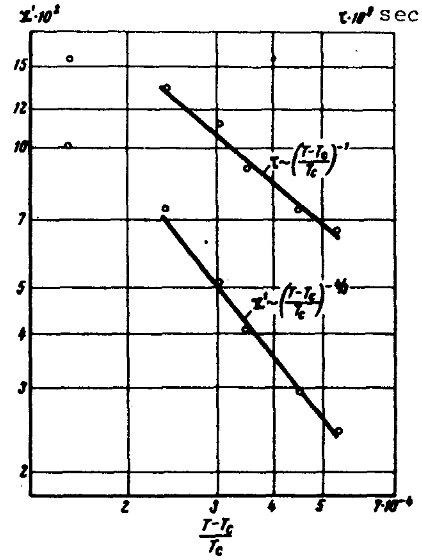

Fig. 2. Temperature dependences of the susceptibility χ' and of the relaxation time τ.

the half-width of the rèsonance curve.

Figure 1 shows the results of measurements of the polarization of the neutrons of wavelength (3 - 6) Å passing through the sample and of the magnetic losses at frequencies 600 - 1400 kHz, as functions of the sample temperature.

It follows from these data that in ferrodielectrics, as well as in metals near T_c, large scale magnetization fluctuations are observed, and the singularities in the P/P_0 curves, i.e., the inflection of the curve, is observed for all neutron velocities at the same temperature, within ±0.01°C. The neutron depolarization increases with increasing wavelength, in qualitative agreement with the Halpern-Holstein formula [4]. Attention is called to the fact that the magnetic-loss maximum coincides within 0.01°C with the singularities of the depolarization curves. The Curie point is thus identified by different physical measurements with a large degree of reliability and accuracy.

The wavelengths of the oscillations propagating in the sample amounted to hundreds of emters in the indicated frequency range. The magnetic field can therefore be regarded as homogeneous (accurate to within the value of the demagnetizing field). In this case the phenomena in the critical region can apparently be described by the gasdynamics equations [5, 6]. We then obtain for the magnetic susceptibility in the paramagnetic region at $\omega\tau \ll 1$

$$\chi(\omega) = \chi(0)(1 + i\omega\tau) = \chi(0) + i\chi''(\omega). \quad (1)$$

Here τ is the time of homogeneous relaxation (i.e., in a uniform field) of the spin system. The homogeneous relaxation in the paramagnetic region is connected with interactions that do not conserve the total spin (dipole-dipole and spin-lattice interactions). As follows from the value of ωτ, an estimate of which is given below, the inequality is satisfied in the frequency interval used by us. If $4\pi\chi(\omega) \ll 1$, then the magnetic permeability of the sample is $\mu = 1 + (4\pi - N)\chi(\omega)$, and the demagnetization thus leaves the temperature dependence of the susceptibility unchanged (N is the demagnetization factor).

The reciprocal of the figure of merit of the circuit is

$$Q_c^{-1} = Q_{pair}^{-1} + Q_{mag}^{-1}, \quad (2)$$

where Q_{par}^{-1} is connected with the parasitic losses in the circuit and Q_{mag}^{-1} is connected with the loss due to reversal of the sample magnetization. At $4\pi\chi(\omega) \ll 1$ we have

$$Q_{mag}^{-1} = (4\pi - N)\chi''(\omega). \quad (3)$$

The static susceptibility χ(0) was determined by measuring the coil inductance. The dependence of χ(0) on $(T - T_c)/T_c$ is shown in Fig. 2, and is well described up to a value $(T - T_c)/T_c \simeq 10^{-4}$ by the power law $\chi(0) \sim [(T - T_c)/T_c]^{-\gamma}$, with $\gamma = 4/3$, in accord with the predictions of similarity theory. At $(T - T_c)/T_c < 10^{-4}$ we have $4\pi\chi(0) \geq 1$ and, as can be seen from Fig. 2, the demagnetization alters strongly the temperature dependence of $\chi(0)$.

For measurements of the circuit Q at nine frequencies in the indicated interval, we determine the value of $\chi''(\omega)$ from formulas (2) and (3). The frequency dependence of $\chi''(\omega)$ turned out to be linear in accord with (1), thus confirming the validity of the hydrodynamic description of the long-wave fluctuations in the critical region.

The value of the relaxation time τ in the critical region at $T > T_c$ in the relative-temperature range 10^{-3} - 10^{-4} lies in the interval 10^{-9} - 10^{-8} sec. A plot of τ against $(T - T_c)/T_c$ is also shown in Fig. 2. According to our data, the dynamic critical index λ, defined by the relation $\tau \sim [(T - T_c)/T_c]^{-\lambda}$, is close to unity, whereas similarity theory predicts $\lambda = 5/3$.

Thus, the measurements have shown that the radio-frequency method is effective and sufficiently precise in investigations of phase transitions in ferrodielectrics. The hypothesis that the hydrodynamic description of homogeneous fluctuations is applicable near T_c was experimentally confirmed. The times of homogeneous relaxation of the spin system in the paramagnetic region and the values of the critical indices were determined.

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RESONANT INTERACTION BETWEEN ORTHO- AND PARA-EXCITONS WITH PARTICIPATION OF PHONONS IN A Cu_2O CRYSTAL

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As is well known, in the Cu_2O crystal there should exist, besides the triply-degenerate exciton state n = 1 of the "yellow" series, with symmetry Γ_{25}^{+} (ortho-exciton) also a nondegenerate state n = 1 with symmetry Γ_2^{+} (para-exciton) [1]. In the luminescence and absorption spectra it is possible to observe only transitions to the Γ_{25}^{+} ortho-exciton levels, which are allowed in the quadrupole approximation [2, 3]. The transition to the Γ_2^{+} state is forbidden in the dipole and quadrupole approximations, so that this state was not observed to date.

The luminescence spectrum of Cu_2O contains, besides resonant emission of the Γ_{25}^{+} exciton, also a number of bands due to annihilation of the exciton with simultaneous excitation (or vanishing) of phonons. According to [1], transitions to the level Γ_{25}^{+} with participation of the phonons Γ_{25}^{-}, Γ_{12}^{-}, Γ_2^{-}, and Γ_{15}^{-} are allowed in the dipole approximation. An investigation of the Cu_2O exciton-