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.

In conclusion, we are grateful to D.M. Kaminker, S.V. Maleev, and A.I. Okorokov for useful discussions and for help with the work.

[1] G.M. Drabkin, E.I. Zabidarov, Ya.A. Kasman, and A.I. Okorokov, Zh. Eksp. Teor. Fiz. 56, 478 (1969) [Sov. Phys.-JETP 29, 261 (1969)].
[2] H. Rauch, E. Seide, and Z. Zeilinger, Zeit. Ang. Phys. 32, 109 (1971).
[3] K.P. Belov and N.V. Shebaldin, ZhETF Pis. Red. 7, 268 (1968) [JETP Lett. 7, 208 (1968)].
[4] O. Halpern and T. Holstein, Phys. Rev. 59, 960 (1941).
[5] B.I. Halperin and P.C. Hohenberg, Phys. Rev. 177, 952 (1969).
[6] M.A. Krivoglaz, Dokl. Akad. Nauk SSSR 118, 51 (1958) [Sov. Phys.-Dokl. 3, 61 (1958)].

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

E.F. Gross, F.I. Kreingol'd, and V.L. Makarov
Leningrad State University
Submitted 23 February 1972
ZhETF Pis. Red. 15, No. 7, 383 - 386 (5 April 1972)

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-luminescence spectra has made it possible to determine the frequencies of all the optical phonons, including that of the Γ_{25}^{+} vibration active in the Raman scattering (see the table). A detailed discussion of the results of the investigation of the Cu_2O phonon spectra will be presented in a separate paper.

Frequencies of optical phonons of cuprous oxide, determined from measurements of the luminescence spectra, and their interpretation

Mode	Γ_{25}^{-}	Γ_{12}^{-}	Γ_{2}^{-}	Γ_{25}^{+}	Γ_{15}^{-}		Γ_{15}^{-}	
					long.	transv.	long.	transv.
Frequency cm^{-1}	84	110	350	515	150	–	640	610

In addition to the phonon modes listed in the table, we observed also one emission band located approximately 180 cm^{-1} away from the ortho-exciton line, and having the characteristic shape of the phonon mode of the free exciton. This band does not fit the general scheme of the phonon spectrum of cuprous oxide. The temperature dependence of the luminescence intensity of this band differs strongly from the temperature dependence of the remaining phonons. In addition, the phonon mode with frequency 180 cm^{-1} is never encountered in the emission spectrum of the bound excitons of cuprous oxide.

All this allows us to propose that the observed band is the result of the interaction between the phonon and another exciton state (not Γ_{25}^{+}). It is natural to assume that this state is the para-exciton Γ_{2}^{+}. It follows from group-theoretical considerations that the transition to the para-exciton level is possible in the dipole interaction when only one phonon Γ_{25}^{-} takes part. Knowing the energy of the Γ_{25}^{-} phonon (ω = 84 cm^{-1}), we determined the position of the para-exciton level (λ = 6135 Å at T = 4.2°K) and the ortho-para splitting energy ε = 96 cm^{-1}. We note that according to the estimate in [1] the magnitude of the ortho-para splitting should be about 15 cm^{-1}.

Although we know where the para-exciton level should be located, we could not observe it in either luminescence or absorption.

We succeeded in observing this level only in deformed crystals. The new line appeared in the Cu_2O luminescence spectrum following compression along the fourfold symmetry axis C_4 at exactly the location determined beforehand, i.e., on the long-wave side of the ortho-exciton line, at a distance 96 cm^{-1}. It turned out that the para-exciton line is emitted not at all pressures, but only starting with a certain definite value, and further increase of the pressure changes its intensity little.

The figure shows microphotographs of the exciton emission spectra at pressures P ≈ 7 kg/mm^2 (curve 1) and P ≈ 10 kg/mm^2 (curve 2). It is seen from the figure that the para-exciton line appears only at a pressure near 10 kg/mm^2. It is known from [4] that when Cu_2O is deformed along the C_4 axis the level of the Γ_{25}^{+} exciton splits into two components, which shift in opposite directions away from the initial position. Corresponding splittings and shifts are experienced also by the phonon replicas. At low temperatures (T ≈ 1.8°K) the short-wave exciton-emission component in the luminescence spectrum is very weak, since it is almost unpopulated. Accordingly, the short-wave components of the phonon replicas are likewise weak and cannot be seen in the luminescence spectra shown in the figure. With increasing pressure (curve 2), however, a new narrow para-exciton line appears in the luminescence spectrum on the short-wave side of the Γ_{12}^{-} phonon.

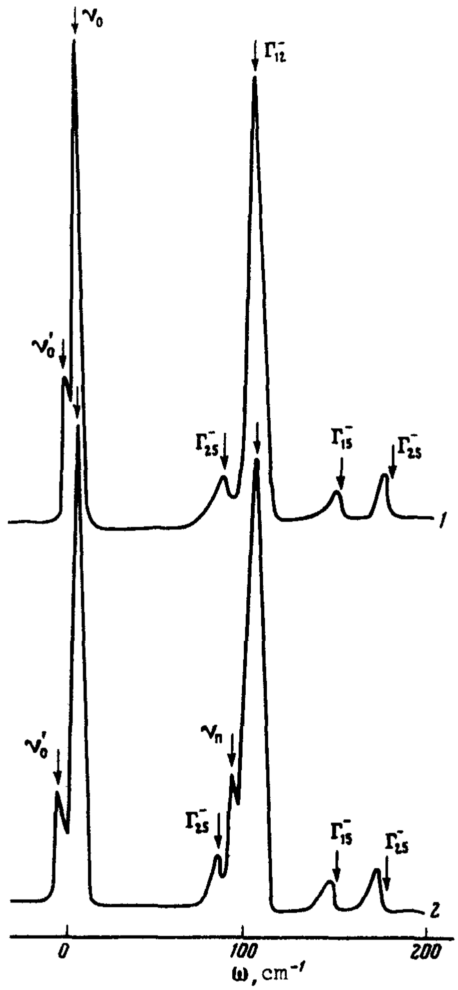
The appearance of the para-exciton line in the Cu_2O luminescence spectrum cannot be due to a lowering of the degree of forbidenness by the deformation [1]. It is likewise impossible to attribute the lifting of the forbidenness to the nonmonotonic pressure dependence of the para-exciton line intensity.

It must be emphasized once more that the appearance of the para-exciton line in the luminescence spectrum has a resonant character. As noted earlier, the para-exciton line appears only when the distance between the short-wave component of the ortho-exciton and the para-exciton level becomes equal to the energy of the Γ_{12}^- phonon (ω = 110 cm^{-1}), i.e., when the short-wave component of the phonon mode of the ortho-exciton happens at the para-exciton level. We have established that the para-exciton phonon-mode intensity is independent of the pressure, and therefore the appearance of the Γ_2^+ line in the emission spectrum can likewise not be attributed to an increase of the para-exciton concentration.

We believe that the appearance of the para-exciton line in the specturm of deformed Cu_2O is due to resonant scattering of the ortho-exciton by the para-exciton level with excitation of a phonon, followed by a radiative transition to the ground state.

In conclusion, the authors are deeply grateful to Professor S.A. Moskalenko and M.I. Shmiglyuk for a discussion of problems in the theory of ortho- and para-excitons in Cu_2O crystals.

[1] R.I. Elliott, Phys. Rev. 124, 340 (1961).
[2] E.F. Gross and A.A. Kaplyanskii, Fiz. Tverd. Tela 2, 379 (1960) [Sov. Phys.-Solid State 2, 353 (1960)].
[3] E.F. Gross and F.I. Kreingol'd, ZhETF Pis. Red. 7, 281 (1968) [JETP Lett. 7, 218 (1968)].
[4] E.F. Gross, A.A. Kaplyanskii, and V.T. Agekyan, Fiz. Tverd. Tela 4, 1009 (1962) [Sov. Phys.-Solid State 4, 744 (1962)].



Microphotographs of the luminescence spectra of single-crystal Cu_2O at pressures P ≈ 7 kg/mm² (1) and ≈ 10 kg/mm² (2); the ortho-exciton lines are marked ν_0 and ν_0', and the para-exciton line ν_p. The phonon frequency ω is reckoned from the unshifted position of the ortho-exciton level. T = 1.8°K, P || C_4.

THE NEW ISOTOPE Tl^{189}

T.B. Vandlik, Ya. Vandlik, N.G. Zaitseva, Z. Mate, I. Mahunka, M. Mahunka, T. Fenyes, H. Tyrroff and M. Jahim
Joint Institute for Nuclear Research
Submitted 23 February 1972
ZhETF Pis. Red. 15, No. 7, 386 - 389 (5 April 1972)

The purpose of the present study was a search for the new isotope Tl^{189}. The level scheme of the daughter isotope is unknown.