connection is (here $p_\pi \gg (m_\pi/m_d)p$):

$$\left.\frac{d\sigma}{dq\,d\Omega_q\,dp}\right|_{p=p_0} = \frac{q p'_\pi}{k q'} \frac{d\sigma_{\gamma d}/d\Omega_q}{d\sigma'_{\pi d}/d\Omega'_{q'}} \left.\frac{d\sigma'}{dq'\,d\Omega'_{q'}\,dp'}\right|_{p' \doteq p_0} \tag{9}$$

where $d\sigma'_{\pi d}/d\Omega'_{q'}$ is the differential cross section of the process $\pi^+ + d \to p + p$.

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* Here and throughout we have in mind the ground state of the nucleus.

EXCITON LUMINESCENCE IN Cu_2O CRYSTALS

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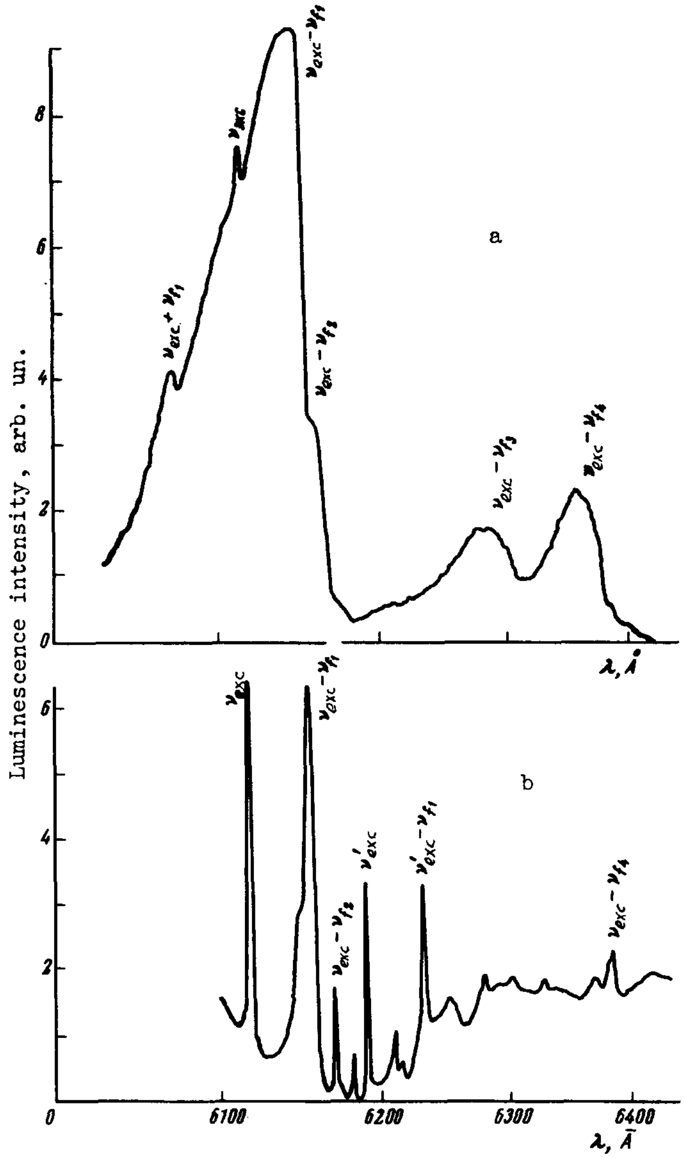
Investigations of crystal edge-luminescence spectra yield abundant information on the band structure, the phonon spectrum, and the nature of the defects. Therefore a study of the luminescence of so well-investigated a crystal as cuprous oxide is of great interest. The band scheme of the Cu_2O crystal and its exciton structure were determined by a number of workers by different methods and with a great degree of completeness (see, for example, [1]). However, in spite of numerous attempts, exciton luminescence was never observed in Cu_2O, although the well known infrared luminescence of this crystal was clearly observed [2]. This was quite puzzling, since exciton luminescence is easily observed in other crystals (Si, CdS, ZnS, CuCl, GaP, and others).

We succeeded in finally observing exciton luminescence in Cu_2O crystals grown (from solutions) by a method employed by one of us (F. K.) in investigations of Ag_2O crystals [3].

The luminescence of Cu_2O was investigated at T = 77 and 4.2°K. The luminescence spectrum at T = 77°K reveals a narrow resonance line dure to annihilation of the first term of the "yellow" series of the Cu_2O exciton. In addition, the spectrum contains a number of bands, the most intense of which is at λ = 6169 Å. A microphotograph of the luminescence spectrum obtained at 77°K is shown in Fig. a. The origin of the luminescence bands observed by us can be explained by taking into account the interaction of the exciton (n = 1) with the phonons. In particular, the λ = 6169 Å band is the result of radiative recombination of the exciton (n = 1) with simultaneous production of a phonon $\nu_{f_1} \approx 107$ cm^{-1}. This value agrees well with the phonon frequency 105 cm^{-1} obtained in the investigation of indirect exciton transitions in absorption [4]. The wavelengths of the Cu_2O luminescence bands at 77°K and their identification are given in the table. The fourth and fifth columns of the table compare the phonon frequencies obtained from the luminescence spectra and the ir absorption spectra.

In the luminescence spectrum of Cu_2O at T = 4.2°K we observed, just as in the case at 77°K, resonance emission of the first member of the "yellow" series of the exciton and a number of bands due to simultaneous emission of an exciton and a phonon. A microphotograph of the luminescence spectrum obtained at T = 4.2°K is shown in Fig. b. Cooling to 4.2°K shifts the exciton resonance emission line from λ = 6127 Å (T = 77°K) to λ = 6099 Å. The



Microphotograph of the luminescence spectrum of Cu_2O crystals: a - at 77°K, b - at 4.2°K.

Position of luminescence lines in Cu_2O at T = 77°K, values of phonons $\nu_{exc} - \nu$, and their comparison with ir absorption data [5,6]

λ, Å	ν, cm^{-1}	$\nu_{exc} - \nu$	ν_f [5,6]	Interpretation
6087	16428			$\nu_{exc} + \nu_{f_1}$
		109	110	
6127	16319			ν_{exc}
		107	110	
6169	16212			$\nu_{exc} - \nu_{f_1}$
		151	147	
6185	16168			$\nu_{exc} - \nu_{f_2}$
		491	485	
6318	15828			$\nu_{exc} - \nu_{f_3}$
6384	15664	655	660	$\nu_{exc} - \nu_{f_4}$

emission bands of the exciton (n = 1) with simultaneous production of the phonons ν_{f_1}, ν_{f_2}, and ν_{f_4} have respective wavelengths 6141, 6156, and 6355 Å.

Besides the phonon satellites of the exciton (n = 1), the luminescence spectrum of Cu_2O reveals at 4.2°K also a series of narrow lines and bands. The two most intense narrow luminescence lines correspond to λ = 6175 Å and λ = 6216 Å. Attention is called to the fact that the distance between these lines is 108 cm^{-1}, i.e., it coincides with the magnitude of the phonon that interacts most strongly with the exciton. These lines disappear simultaneously if the crystal is heated slightly (by ~10°) above 4.2°K. The narrowness of the lines and their temperature dependence suggest that one of them is due to the emission of a bound exciton (λ = 6175 Å), and the other (λ = 6216 Å) is its phonon satellite.

Additional investigations are needed for the identification of the remaining luminescence bands observed at T = 4.2°K.

It must be noted that, so far, we have not observed lines corresponding to emission of the exciton of the "green" series and of higher members of the "yellow" series.

An investigation of the luminescence of Ag_2O crystals at T = 77°K has shown that in these crystals, as well as in Cu_2O, exciton luminescence as well as its phonon satellites are observed.

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