and would be of great interest since the density difference between the two phases should be considerably reduced. Recombination radiation studies have been reported by Bageev, Galkina, and Gogolin,[1] which indicate a large reduction in metallic state binding. Benoit à la Guillaume, Salvan, and Voos[15] have measured a density of 2×10^{16} cm^{-3} in the metallic phase which is somewhat larger than the value of 1.2×10^{16} cm^{-3} that we find.

In conclusion we find that the large binding energy of the metallic state of the electron-hole liquid in Ge is due mainly to its special band structure. For simple band structure, such as in strained Ge, the binding is much weaker if indeed the metallic phase is bound. A detailed account of the calculations reported here will be published elsewhere.

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*Present address: Department of Physics, Princeton University, Princeton, N. J. 08540.

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Normal Modes of Vibrations in CuI

B. Hennion and F. Moussa

Service de Physique du Solide et de Résonance Magnétique, Centre d'Etudes Nucléaires de Saclay, 91 Gif-sur-Yvette, France

and

B. Prevot, C. Carabatos, and C. Schawb

Laboratoire de Spectroscopie, Institut de Physique, Université Louis Pasteur, 67-Strasbourg, France

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Phonon dispersion curves for CuI have been measured at room temperature for the [100], [110], and [111] symmetry directions by using inelastic neutron scattering. The results are interpreted in terms of a rigid-ion model. Estimations are given for elastic constants.

Continuing the study of the lattice dynamics of cuprous-halide crystals with zinc-blende structure, we report in this paper the results of coherent inelastic neutron scattering from CuI.

Our interest in these compounds dates from some years ago, since the unfruitful attempt to fit zero-wave-vector phonons of CuCl with an oversimplified rigid-ion-lattice dynamical model.[1] Mar-

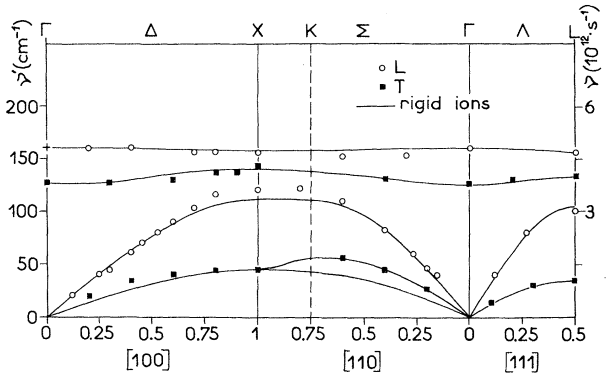

FIG. 1. Experimental and theoretical dispersion curves for CuI.

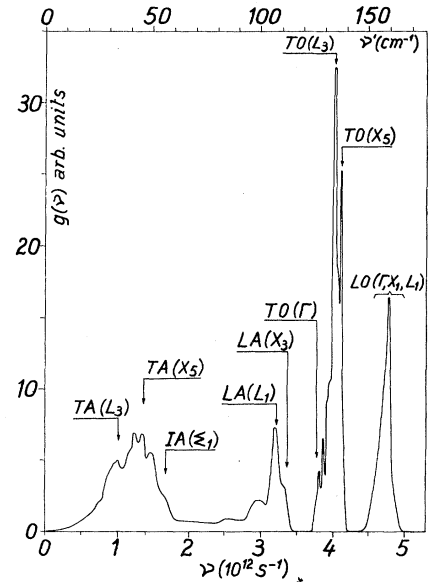

FIG. 2. Phonon density of states for CuI according to the rigid-ion model.

tin[2] pointed out the peculiar behavior of CuCl relative to other crystals with the same symmetry. In a previous paper, Carabatos *et al.*[3] emphasized both the curious shapes of experimental dispersion curves of CuCl (namely, in the [110] direction) and serious difficulties in the attempts to fit usual theoretical models to the measured curves. Supposing a possible interaction between $3d$ electrons of neighboring copper ions in CuCl, we decided to study the phonon dispersion curves in CuI where, the iodine ionic radius being greater than that of chlorine, this interaction should decrease.

All the measurements were done on the triple-axis spectrometer of the EL3 reactor at Centre d'Etudes Nucléaires de Saclay. The monochromator and the analyzer were, respectively, germanium and copper single crystals. According to the shape of the dispersion curves, we used either the Q-constant (for flat branches) or the ν-constant technique for waves propagating along the high-symmetry directions [100], [110], and [111]. The first measured phonons and a rigid-ion model were used to calculate approximate inelastic structure factors in order to optimize the search of new phonons, particularly for optical branches.

The sample was prepared by one of us (C.S.) using the flux-growth technique. It had a volume of about 2.5 cm^3 and was a part of a cylinder 1.6 cm in diameter and 2.5 cm long. The cylinder axis was approximately parallel to a $\langle 110 \rangle$ crystallographic axis. The crystal purity was determined by spectrochemical analysis with the following results: Ca $\simeq 3\times10^{-5}$, Fe and K $\simeq 10^{-5}$, Mg $\simeq 5\times10^{-6}$, and Ag $\simeq 10^{-6}$ per weight; its mosaicity was estimated to be better than 0.1°.

Most of the determinations were made at room temperature with the $(1\bar{1}0)$ planes horizontal and parallel to the momentum of the neutrons. Some phonons were also measured at 90°K at the X, L, and Γ points of the first Brillouin zone.

Experimental results at room temperature are shown in Fig. 1 together with a rigid-ion–model fit using six short-range parameters. The agreement is surprisingly good, considering the simplicity of the model and compared with the results for CuCl.[3] The transverse-optical frequency at the Γ point previously found by infrared absorption and reflectivity measurements[4] agrees well with our neutron results within 2%. The main differences with the observations in CuCl are the disappearance of the singular shape of the pseudo-LA branch in the [110] direction, and the non-crossing of optical branches. In Fig. 2 is given the phonon density of states obtained with the help of an extrapolation method[5] using 527 crude mesh cubes uniformly distributed in $\frac{1}{24}$ of the first Brillouin zone. From the initial slopes of the acoustical branches, we have estimated the elastic constants of CuI; the results as well as the rigid-ion–model parameters are summarized in Tables I and II.

At 90°K, we have observed an increase in the frequencies of about 8 cm^{-1} for TA and LA phonons at the X point and of 10 cm^{-1} for the LA at the L point; for the Γ point, only the ω_{TO} frequency was accurately measured, giving a shift of 8 cm^{-1} toward increasing energies. It must

TABLE I. Experimental values of the Reststrahlen frequencies and elastic constants of CuI; values in parentheses are relative to 90°K measurements. The uncertainty in the elastic constants is ±10%

C_{44}	C_{12} (10^{12} dyn/cm^2)	C_{11}	ν_{LO}' (cm^{-1})		ν_{TO}' (cm^{-1})		Source
...	...	...	(224)[a]	211[a]	(132)	124.2	Ref. (4)
0.158	0.305	0.405	(168)	160	(134)	126	This work

[a]Deduced by the Lyddane-Sachs-Teller relation and dielectric constants given in Ref. (4).

be noted that these displacements are just indicative, because they are only slightly greater than the uncertainty of the measurements at these points.

In conclusion, and before any fitting with a more complete model, we may consider our hypothesis concerning the influence of the overlap and hybridization of the 3*d* electron wave functions in cuprous halides as likely to be true; considering the ionic radii of chlorine, bromine and iodine, CuBr should present an intermediate behavior.

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TABLE II. Rigid-ion–model parameters for CuI; force constants are in e^2/v (v is the volume of a unit cell). $Z_{Cu}^* = 0.69$.

1	s		s'	α	β	$\Phi_{\alpha\beta}(0_s; 1_{s'})$
(0, 0, 0)	1		2	1	1	2.812
		or				
	2		1	1	2	3.734
				1	1	0.562
	1		1	1	2	0.393
$\frac{1}{4}a(2, 2, 0)$		or				
	2		2	1	3	−0.253
				3	3	−0.6

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Direct Optical Observation of the Subsidiary X_{1c} Conduction Band and Its Donor Levels in InP

A. Onton, Y. Yacoby,* and R. J. Chicotka
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598
(Received 7 February 1972)

Zero-phonon and phonon-assisted optical transitions from the Γ_{1c} conduction band to the subsidiary X_{1c} conduction band and its donor levels have been observed in InP at 8°K. The X_{1c}-Γ_{1c} interband energy is measured at 960 ± 5 meV, and the binding energies of donors associated with the subsidiary X_{1c} band are found to be 106 and 175 meV (±5 meV) for Te and Si, respectively.

We report here on a measurement of the $\Gamma_{1c} \rightarrow X_{1c}$ inter-conduction-band energy in InP by means of optical absorption, utilizing the wavelength-derivative technique. The interband free-carrier absorption in InP has been measured by Dumke, Lorenz, and Pettit.[1] With the present measurement technique we have observed for the first time phonon structure associated with the $\Gamma_{1c} \rightarrow X_{1c}$ indirect transition in degenerately doped InP, as well as transitions from the Γ_{1c} conduction band to donor levels associated with the subsidiary X_{1c} conduction-band minima.