CREATING OF EXCITON DROP SIN THE EXCITON-P HNON FIELD

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The object of our investigations is the fusion of two Frenkel excitons at one lattice point which could appear due to virtual echange of phonons, i.e. the forming of exciton drops (see /1/). The Hamiltonian of the exciton-phonon interaction will be taken in the approximation of the very strong coupling (see /2/):

$$H_{int} = \int d^3\vec{k}\, d^3\vec{q}\, F(\vec{q}) B^+_{\vec{k}-\vec{q}} B_{\vec{k}} (b_{\vec{q}} + b^+_{\vec{q}}); \quad F(\vec{q}) = i\left[\frac{\hbar \Delta^2}{16\pi^3 M v q}\right]^{1/2} \vec{q}\,\vec{l}_{\vec{q}} \tag{1}$$

Here B, B^+ and b, b^+ are the exciton and phonon operators, respectively, Δ - is the excitation energy of an isolated molecule, $\vec{l}_{\vec{q}}$ - is the phonon polarization vector and v-the velocity of the longitudinal sound waves. The details about the Hamiltonian (1) are given in /2/.

The complete Hamiltonian of the system can be written as follows:

$$H = H_{exc} + H_{ph} + H_{int} \tag{2}$$

where H_{int} is given by the formula (1), and

$$H_{exc} = \int d^3\vec{k}\, \mathcal{E}(\vec{k}) B^+_{\vec{k}} B_{\vec{k}}; \qquad H_{ph} = \int d^3\vec{k}\, \hbar v k\, b^+_{\vec{k}} b_{\vec{k}} \tag{3}$$

are the exciton and the phonon Hamiltonian, respectively.

By the use of the unitary Frölich's transformation we can go over from (2) to the equivalent Hamiltonian in which, instead of exciton-phonon interaction, figure a fourth order term with the attractive interaction between excitons.

The attractive interaction in the exciton system can cause the fusion of two excitons at one lattice point. The complete process can be imagined as follows: due to the attractive forces two excitons are captured by a molecule and mouve in the potential well of depth 2Δ, approximately. After a time molecule unloads emitting two photonlike quanta. The spectrum of these qualitatevely new excitations will be analysed in forther.

Extracting from the equivalent Hamiltonian the part which is responsible for the capturing processes we obtain:

$$H_c = \Delta \int d^3\vec{k}\, B^+_{\vec{k}} B_{\vec{k}} + \frac{1}{(2\pi)^3} \int d^3\vec{k}\, d^3\vec{q}\, T(\vec{k},\vec{q}) B^+_{\vec{k}} B^+_{-\vec{k}} B_{\vec{q}} B_{-\vec{q}} \qquad (4)$$

where

$$T(\vec{k},\vec{q}) = \frac{2m^2\Delta^2}{\hbar^2 M}\left[(\vec{k}-\vec{q})^2 - k_o^2\right]^{-1}; \quad k_o = \frac{2mv}{\hbar} \sim 10^5 cm^{-1} \qquad (5)$$

Following the ideas of Bogoliubov, successfully used in the theory of superfluidity, we go over from the operators B, B^+ to the new Bose operators C, C^+ by the use of the usual Bogoliubov's "u-v" transformations. The mixing of Bose amplitudes enables as to extract from the interaction term in (4) the quadratic part in new operators C^+C, which corresponds to the above mentioned new excitations.

The spectrum obtained in this way is of the form:

$$\lambda(x) = \Delta\left(1 - \frac{\sin^2 x}{x^2}\right)^{1/2}; \quad x \equiv k r_o; \quad r_o \equiv \frac{\pi}{2k_o} \sim 10^{-5} cm. \qquad (6)$$

The analysis of (6) shows that for the small momenta the excitations have the linear dispersion law:

$$\lambda \approx c_o \hbar k; \qquad c_o = \sqrt{\frac{2}{3}}\, \frac{r_o \Delta}{\hbar} \sim 10^{10}\, cm\, s^{-1} \qquad (7)$$

which corresponds to the light quanta. The characteristic minimum at the large momentum range, analogous to the rotonic one in the theory of liquid He^4, indicates that the new excitations have the superfluid properties.

References:

/1/ V.M.Agranovich, "Theory of Excitons" Nauka, Moscow 1968 (p.363; p.357) (in Russian).

/2/ D.V.Kapor, S.D.Stojanović, M.J.Škrinjar and B.S.Tošić, Phys. Stat. Sol. (b) 74, 103 (1976).