EFFECT OF EXCITON INTERACTION ON EXCITON SPECTRA

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We consider light absorption accompanied by conversion of excitons into biexcitons. We show that it has a gigantic oscillator strength.

1. Exciton interaction can cause them to become aggregated into biexcitons [1], polyexcitons [2], and drops [3]. These objects are being diligently studied (for reviews see [4]). The predominant type of aggregate is determined by the detailed form of the semiconductor band structure. However, in view of the complexity of the situation and of the simultaneous existence of different aggregates, it is still impossible to set individual bands in unique correspondence with definite aggregates in a number of cases.

Experimental studies of the aggregates are usually performed under conditions when the total number of excitons is either constant (infrared absorption, scattering of light by drops, etc.) or decreases by unity (luminescence). Yet it would seemingly be very useful to investigate transitions in which the total number of excitons increases and the phototransition produces more complicated complexes. We are dealing essentially in this case with a special type of induced absorption. Related effects have already been investigated [5]. It is very important, however, that it is precisely for exciton transitions that this absorption must be characterized by two important features: it can have a distinct structure and must have a gigantic oscillator strength. The present article is devoted to these features. In passing, we estimate the probability of the radiative recombination of biexcitons.

2. We consider first a semiconductor with direct allowed transitions and with a bound state (binding energy E_b) of two excitons, corresponding to a biexciton. Then if the crystal contains an exciton with momentum $\vec{K}$, light absorption is possible such that the produced exciton is bound to the initial exciton, i.e., the absorption of light leads to a conversion of the exciton into a biexciton having the same momentum $\vec{K}$. If $E_b \ll R$, where R is the exciton Rydberg constant, then it can be assumed that the excitons are not strongly deformed when they combine into a biexciton, and the oscillator strength f_b (per exciton) for this process can be expressed in terms of the oscillator strength f_{ex} of the ordinary exciton absorption (per unit cell):

$$f_b = \frac{2}{v}\left| \int d^3 r\, \Phi(r) \exp(iKr/2) \right|^2 f_{ex}. \tag{1}$$

Here $\Phi(\vec{r})$ is the function of internal motion in the biexciton, and vi is the volume of the unit cell. If we assume a short-range interaction between excitons and use the deuteron approximation, we obtain

$$f_b(K) = \frac{f_b(0)}{[1+(K/2\kappa)^2]^2}, \quad f_b(0) = \frac{16\pi}{v\kappa^3} f_{ex}, \tag{2}$$

where $\kappa = \sqrt{mE_b}/\hbar$ is the reciprocal biexciton radius and m is the exciton mass.

Since we have $v\kappa^3 \ll 1$ at the usual $E_b \sim 10^{-2} - 10^{-3}$ eV, it follows that $f_b(0) \gg f_{ex}$, i.e., the oscillator strength is large. The nature of this effect is exactly the same as for impurity excitons [6]. We can therefore expect on the basis of the available experimental data $f_b \sim 10$ and small radiative-recombination times $\tau \sim 10^{-9}$ sec.

The only significant difference from impurity excitons is that the transition frequency contains the term $\hbar^2K^2/2m$, which leads to a broadening of the absorption band and to a shift of its maximum towards the low-frequency side relative to the threshold. The band contour is described by the formula

$$\sigma \sim \frac{\sqrt{\Omega}}{[1+\Omega/E_b]^2} \exp\{-2\Omega/T\}, \tag{3}$$

$$\Omega = \omega_{thr} - \omega > 0, \quad \omega_{thr} = E_g - R - E_b.$$

At $T \lesssim E_b$, observation of this band should make it possible to determine E_b, and owing to the high values of f_b such measurements are possible at relatively low exciton concentrations. A comparison with the luminescence spectra should make it possible to separate reliably the biexciton spectrum.

3. There is no analogous effect for indirect transitions. In crystals with indirect transitions, however, there can exist additional extrema corresponding to direct transitions, as is the case with Ge. Photoproduction of a direct exciton near a thermalized indirect one is then possible, and the two can form a biexciton. The oscillator strength of such a transition will also be gigantic and described by a formula that differs only slightly from (2) (mainly because of the difference between the exciton masses).

The situation should be particularly interesting if a confirmation is found for the polyexciton idea [2], according to which the binding energy in multivalley crystals increases progressively with increasing the number N of the excitons contained in the crystal. In this case the width of the absorption band corresponding to the "completion" of the polyexciton on account of the direct exciton, should be small ($\sim N^{-1}$) owing to the large mass of the polyexciton.

Thus, in crystals with indirect transitions one can expect to observe aggregates that do not appear under quasiequilibrium conditions. Since drops cannot generate the structural spectra considered here, these spectra can be useful for the study of the composition of a quasiequilibrium phase.

4. We note in conclusion that in addition to the absorption connected with transitions to a discrete biexciton level, there exists an absorption corresponding to transitions to the continuous spectrum of a system of two excitons. It also contains a large factor $(\kappa^3 v)^{-1} \gg 1$, and furthermore diverges like $[\omega - (E_g - R)]^{-2}$ near the frequency corresponding to the production of a free exciton (on both sides of this frequency). Although the divergence is cut off by the exciton damping and by the polariton effect, its intensity is nevertheless large. Equally large is the probability of the inverse process, collision emission.

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0^+ STATE OF ALPHA PARTICLE IN A MODEL WITH SEPARABLE POTENTIAL

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We consider in this article a new approach to the four-nucleon problem, based on the use of multiparticle integral equations. This approach is free of the shortcomings of the usual variational methods [1] and is equally applicable to the calculation of discrete and continuous spectra. In particular, it is easy to obtain in this method practically exact results for states of the cluster type, for which the method of hyperspherical functions [2] results in worse convergence and needs to be modified [3]. We present below the first calculations of this kind for 0^+ states of an α particle with allowance for the spin dependence of the nucleon-nucleon interaction. It must be emphasized that allowance for spin effects makes the solution method much more complicated in comparison with the earlier "spinless" calculations of few-nucleon systems. On the other hand, if realistic nucleon-nucleon potentials are used there are no grounds whatever for neglecting forces that depend on the spin orientations. We have considered the variant of integral equations of the Yakubovskii type [4], which take the form of