Optical Functions of Rydberg Excitons

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Recently Rydberg Excitons have attracted more attention [1-3]. After their detection in a natural crystal of copper oxide found at the Tsumeb mine in Namibia [1] an intensive research, both theoretical and experimental, have started. Due to the fact that the optical properties of Rydberg excitons have been experimentally examined, there is a need for theoretical description and interpretation of their unusual features. We show how to compute the optical functions (reflectivity, transmissivity, and absorption) of semiconductor crystals when Rydberg excitons exist, taking into account the effect of the coherence between the electron-hole pair and the electromagnetic field. Our method which based on the so-called real density matrix approach [3]. Having in mind the experimental results, we focus the attention on the optical spectra of Cu_2O. As it follows by the analysis of crystal symmetry, the lines related to odd angular momentum exciton number $\ell = 1, 3, ..$ are observed [2]. The dominant role play the P-excitons (the so-called yellow series), but also excitonic states with higher than $\ell = 1$ angular momentum (for example, the F-excitons with $\ell = 3$ and H- excitons with $\ell = 5$) were observed in one-photon absorption spectra of high-quality cuprous oxide. The method we developed, described in details in ref. [3], allows one to computed not only the energy eigenvalues, but also the line shapes of the optical functions. The presented theory explains many peculiar characteristics of Rydberg excitons such as deviations from n^{-3} law of oscillator strengths or derivation from n^{-2} law for the excitonic energies, gives the polariton dispersion relation. Using anisotropic effective masses, we show the energy splitting of the P, F, and H excitons. Our numerical results are in almost perfect agreement with experimental results obtained by Kazimierczuk *et al.* [1] and Thewes *et al.* [2].

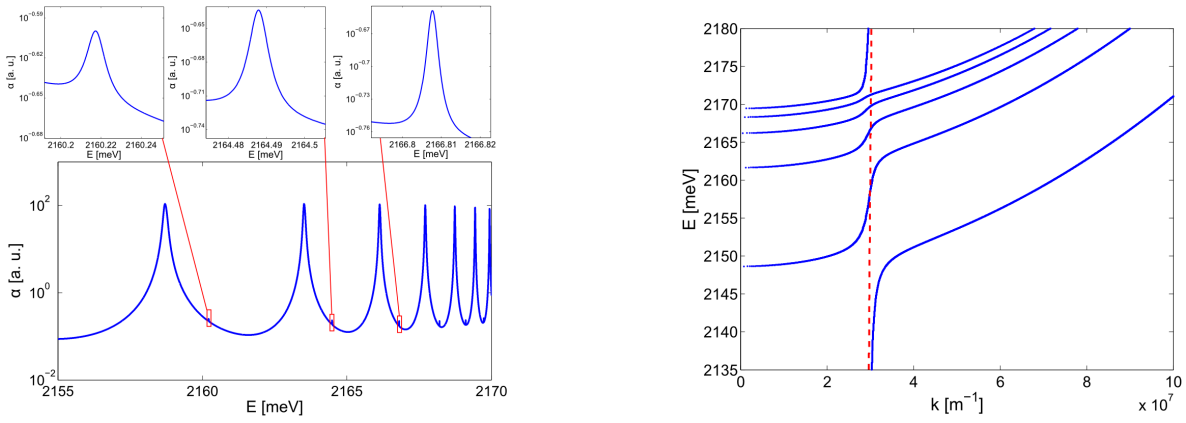

Figure 1: a) The absorption spectra including the effect of P and F excitons. b) The polariton dispersion for a Cu_2O crystal for 5 lowest excitonic states.

[1] T. Kazimierczuk, D. Fröhlich, S. Scheel, H. Stolz, M. Bayer, *Nature* **514**, 344 (2014).
[2] J. Thewes, J. Heckötter, T. Kazimierczuk, M. Aßmann, D. Fröhlich, M. Bayer, M. A. Semina, and M. M. Glazov, *Phys. Rev. Lett.* **115**, 027402 (2015).
[3] S. Zielińska-Raczyńska, G. Czajkowski, and D. Ziemkiewicz, *Phys. Rev. B* **93**, 075206 (2016).