BOSE–EINSTEIN CONDENSATION OF TWO–DIMENSIONAL MAGNETOEXCITONS. THE INFLUENCE OF THE EXCITED LANDAU LEVELS. ENERGY SPECTRUM OF TWO-DIMENSIONAL MAGNETOEXCITONS

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The Bose–Einstein Condensation (BEC) of two-dimensional(2D) magnetoexcitons is a coherent macroscopic state which essentially depends on the structure of the Landau levels of electrons and holes on the ideal monolayer in the strong perpendicular magnetic field. We have took into account explicitly five Landau levels for electrons and holes with quantum numbers $n_e, n_h = 0,1,2,3,4$. The 2D magnetoexcitons in Landau gauge are characterized by the pair of quantum numbers (n_e, n_h) describing the Landau quantization in one in-plane direction and by two uni-dimensional wave vectors p, q describing the free motion in another in-plane direction perpendicular to the previous one. Instead of the pair of wave numbers p, q the magnetoexcitons are characterized by the two-dimensional wave vector $\vec{k}$. The BEC of magnetoexcitons on the single–particle state with wave vector $\vec{k} \neq 0$ was considered. The influence of the excited Landau levels on the collective properties of the high density magnetoexcitons was revealed. To this end the indirect interactions between electrons, between holes and between electrons and holes lying on their lowest Landau levels were deduced. They are due to the simultaneous excitations on the excited Landau levels of the interacting particles during their first step of the Coulomb scattering and to their return back to the initial states during the second step of the scattering process. As a result in the second order of the perturbation theory the indirect interaction appears. Its contributions to the repulsion between the magnetoexcitons and to the stabilization of their BEC was determined. They essentially depend on the value of the condensate wave vector $\vec{k}$ and are important in the range $\vec{k} \approx 0$.

The energy spectrum of four lowest exciton bands characterized by the combinations of the numbers (n_e, n_h) (of electrons and holes) as follows $(0,0);\ (1,0;)\ (0,1);\ (1,1)$. Their wave functions were determined in the first order of the perturbation theory, whereas their energy spectrum in the second order of the perturbation theory. As the perturbations some nondiagonal matrix elements of the Coulomb interaction are considered. They are much less than the diagonal matrix elements.