Superfluid state of magnetoexitons in double layer graphene structures

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The possibility of realization of a superfluid state of bound electron-hole pairs (magnetoexitons) with spatially separated components in a graphene double layer structure (two graphene layers separated by the dielectric layer) subjected by a strong perpendicular to the layers magnetic field is analyzed. The flow of such pairs is equivalent to two counterflow electrical currents in the layers.

In graphene the energies of the Landau levels are given by the expression $E_n = \sqrt{2n}\hbar v_F/\ell$, where $v_F \approx 10^8$ cm/s is the parameter of the electron structure, $\ell = \sqrt{\hbar c/eB}$ is the magnetic length, and $n = 0, \pm 1, \pm 2, \ldots$. In undoped graphene the 0-th Landau level is half filled. We show that an imbalance of filling factors of the layers $\nu_i^{(0)}$ is required to achieve the superfluid state of magnetoexitons (the filling factors $\nu_i^{(0)}$ are defined as the fraction of occupied states in the 0-th Landau level times the spin and valley degeneracy factor $g = 4$). The imbalance can be created by an electrostatic field (gate voltage) applied perpendicular to the layers.

We compute the critical interlayer distance d_c and the superfluid stiffness versus the filling factor imbalance. The maximum superfluid stiffness is achieved for the filling factors $\nu_1^{(0)} = 5/2$, $\nu_2^{(0)} = 3/2$ and $\nu_1^{(0)} = 7/2$, $\nu_2^{(0)} = 1/2$, while the critical distance at such filling factors is minimal (the inequality $d < d_c$ yields the condition of stability with respect to appearance of charge density waves). The spectrum of collective excitations is computed and the dependence of the Berezinskii-Kosterlitz-Thouless transition temperature on the imbalance of the filling factors and on the interlayer distance is found. The case of large gate voltage, when in one layer the $n = 1$ level becomes partially filled and in the other layer the $n = -1$ level becomes partially unfilled, is also analyzed.

The advantages of use graphene double layers instead of double quantum well GaAs heterostructures are discussed. In graphene systems much smaller tunneling between the layers reduces considerable the energy losses. Beside that, lower magnetic fields are required to achieve the superfluid state of magnetoexitons in graphene systems.