Super-long-living spin excitations in a purely electronic two-dimensional gas.

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The lowest-energy excitation in a $\nu = 2$ quantum Hall system is a purely electronic cyclotron spin-flip exciton (CSFE) [1] where electron is promoted from the upper spin sublevel (with 'spin-down') of the zero Landau level to the next Landau level with 'spin-up'. The CSFE energy is well smaller than the cyclotron one: it is separated from upper magnetoplasma mode by a negative Coulomb shift (1mV) and from the ground state by a gap of $\approx 5-7\,$mV. The q-momentum dispersion of the CSFE energy is rather weak and has a smooth minimum at $q = q_0 \approx 1/l_B$ (l_B is the magnetic length [1]). The considerable Coulomb shift consists of two negative contributions: the first one is the zero-momentum $q = 0$ shift determined only by the second-order Coulomb correction [2]; and the second part is the first-order correction at a finite momentum [1]. Both contributions at $q \approx q_0$ are approximately equal. At low temperature (actually at $T < 0.1\,$mK) the CSFE can only relax with the emission of hard acoustic phonons [3]. An extremely long life of the state is determined by the following reasons: (i) the studied relaxation is simultaneously the energy and spin relaxation process – the CSFE is a 'dark' exciton, radiative relaxation is suppressed; (ii) the state is energetically far from the ground state, so emitted phonons possessing a very short wavelength are only weakly coupling to the state. A theoretical estimate yields the characteristic CSFE relaxation time expected to reach several milliseconds. At higher temperatures a radiative mechanism of the relaxation is switched on via thermal-activation transition to the upper magnetoplasma state fast-relaxing radiatively. As a result, experimentally even at $T > 0.4\,$mK the CSFE relaxation (actually the spin relaxation) can occur with the characteristic time of 100 mcs [4] — still super long for unconfined systems consisting of free conduction-band electrons. In the works [4-5] the CSFE relaxation and kinetics are studied both experimentally and theoretically. The dense CSFE ensemble (with the CSFE number N_x reaching ten percents of the number of magnetic flux quanta N_ϕ) is created by means of the resonant photoexcitation pumping. To monitor the CSFE ensemble state, an additional time-resolved technique of the photoinduced resonant absorption/reflection (PRA/R) is employed. Experimentally, at a given CSFE concentration $n = N_x/N_\phi$ above 5 percents a threshold enhancement of the PIRA/R signal is observed when the temperature is dropping below some value $T_0 = T(n)$ within the $0.4\,$K$< T < 1\,$K range. This effect can be explained in the framework of a CSFE-ensemble phase transition to a coherent state — bosonic condensate. Theory describes both incoherent and coherent states in terms of the so-called excitonic representation (see Refs. [2,3] and the Supplementary Note 1 in Ref. [5]) and gives a tenfold increase in the PIRA/R signal during the CSFE-ensemble transition to the condensate state (i.e. to a Bose-condensate formed in a purely electronic system). The theory estimation agrees with the experimental data.

[1] C. Kallin and B.I. Halperin, Phys. Rev. B 30, 5655 (1984).
[2] S. Dickmann and I.V. Kukushkin, Phys. Rev. B 71, 241310(R) (2005).
[3] S. Dickmann, Phys. Rev. Lett. 110, 166801 (2013).
[4] L.V. Kulik , A.V. Gorbunov, A.S. Zhuravlev, V.B. Timofeev, S. Dickmann, & I.V. Kukushkin, Nature Sci. Rep. 5, 10354 (2015).
[5] L.V. Kulik, A.S. Zhuravlev, S. Dickmann, A.V. Gorbunov, V.B. Timofeev, I.V. Kukushkin, S. Schmult, Nature Comm. 7, 13499 (2016).