V. D. Kulakovskiĭ, I. V. Kukushkin, and V. B. Timofeev. *Spin-oriented exciton gas in uniaxially deformed germanium*. The well-known theoretical conception based on integer exciton spin predicts the quantum-statistical behavior of a system of high-density excitons in semiconductors at low temperatures if the short-range repulsion predominates over the van der Waals attraction.[1] For ordinary "atomic" excitons, this behavior is excluded by the dominance of attractive forces, which bind them into excitonic molecules (EM) and an electron hole liquid (EHL).[4] However, the nature of the paired exciton-exciton interaction can be modified by orienting the electron and hole spins in the excitons, e.g., with a magnetic field. The stability of EM's then vanishes owing to the exchange repulsion of these "spin-oriented" excitons at short distances. In this respect, the system of spin-oriented excitons has a far-reaching analogy to the gas of spin-oriented hydrogen atoms[5] and should exhibit a more pronounced quantum behavior than the EM gas.

The above conception is an alternative to the observed phenomenon of exciton condensation in EHLs.[4,6] In undeformed germanium, the bonding energy of the EHL is very large ($\varphi \sim 0.5$ R, where R is the excitonic rydberg).[6] Therefore the exciton gas in such a crystal is a classical gas ($|\mu_{ex}| \gg kT$, where μ_{ex} is the chemical potential of the excitons) throughout the entire region of its coexistence with EHL. The density of the exciton gas in Ge may approach the corresponding quantum limit if the EHL is destablized by very strong uniaxial deformation of the crystals in a direction close to ⟨001⟩. Orbital degeneracy in the electron (hole) bands is lifted under these conditions, thereby lowering the density of states, to which the bonding energy of the e-h liquid is most sensitive. The partial fraction of the EM also increases ($n_M \sim n_{ex}^2$), and a channel corresponding to radiative annihilation of the EM is observed in the emission spectrum. The bonding energy of the EM in Ge is ~0.1 R or ~3 K.[7,8]

Owing to the small scale of the bonding energy, EM in germanium crystals present a highly convenient model for investigation of molecular properties in magnetic fields: for example, the energies of the paramagnetic splitting and the diamagnetic shift in the exciton are already comparable to the EM binding energy in fields $H = 2-3$T. It has been found experimentally that the diamagnetic susceptibility of the EM is about three exciton susceptibilities. Therefore at $T \approx 2$ K in fields $H > 1$ T, when the spin splitting of the exciton terms becomes larger than the binding energy of the EM and the average thermal energy of the excitons, the EM emission line vanishes from the spectrum since spin-oriented excitons cannot form a stable molecular state.[8]

It has also been found experimentally that switching on magnetic fields $H < 5$ T does not significantly stabilize the EHL because of the large value of the diamagnetic correction for Landau diamagnetism.[9] In strongly deformed germanium in magnetic fields $H = 2-3$ T, therefore, we have a unique opportunity to investigate the statistical behavior of the spin-oriented exciton gas all the way up to the densities at which they begin to decompose by ionization. The most important limitations are imposed by the fundamental difficulty of cooling an exciton gas to very low temperatures because of the nonequilibrium nature of the system.

Information on the behavior of the exciton gas as its density varies can be obtained from analysis of the exciton-phonon emission spectra. As n_{ex} increases, the emission line first narrows in accordance with the change in the exciton distribution in the band in accordance with the Bose-Einstein statistics.[10] The interaction between the excitons begins to assert itself at large n_{ex}, and their emission line broadens. An attempt may be made to describe the emission spectrum of the weakly nonideal Bose electron gas in terms of recombination of ideal quasiparticles with a single-particle spectrum restructured by interaction. The dispersion law of the corresponding single-particle spectrum can be found by analyzing the contour of the exciton-phonon emission line.

In the dispersion law found in this way, as we should expect for a weakly nonideal gas, we observe an acoustic branch at small quasi-momenta, and the effective mass of the excitons "dressed" by the interaction increases.

Ionization decomposition of excitons accompanied by a stepwise change in the transport electron properties has been observed at densities corresponding to a dimensionless parameter $r_s \approx 2$.[11]

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