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Quasi-particle excitations in dynamical response of two-dimensional electrons in strong magnetic field

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It has been discussed that the elementary excitation in the fractional quantum Hall (FQH) system has a fractional charge and obeys the fractional statistics. This elementary excitation has been experimentally confirmed in conductance measurements of the system with anti-dot, and moreover, shot-noises in the quantum point contact have been naturally interpreted in terms of carriers with fractional charge. On the other hand, the fractional charge or statistics has been also discussed in some of one-dimensional models. Exact theories with respect to such models tell us that the elementary excitation manifests its nature in the dynamics. For example, the dynamical spin structure factor of the Heisenberg chain is mainly interpreted by two spinons, and the single-particle spectral function of the Calogero-Sutherland model is composed of the spectrum of free quasi-particles and -holes. The circumstance in one-dimensional models make us consider possible manifestations of the elementary excitation in the dynamics of FQH systems.

By now the dynamics has been studied for the density fluctuation of FQH systems. However no indication of quasi-particle excitations is seen in the excitation spectrum. We consider that this is because the attractive interaction between quasi-electrons and -holes makes bound states of them and prevents manifestation of their anyonic feature in the dynamical charge structure factor. On the other hand, in the case of the excitation of single-electron removal, it is expected that the created quasi-holes are free from particle-hole attraction and the spectrum is dominated by only the quasi-hole. On this ground, we study in the present thesis the single-electron spectral function of $\nu = 1/p$ (p = 3, 5) FQH systems and show that characteristic structures due to e/p-charged quasi-holes emerge in the spectrum.

We deal with the Hamiltonian composed of the Coulomb interactions between electron pairs, between the electron and the positive background charge, and between positive background charges. We adopt the symmetric gauge for the vector potential and assume that the positive background charge spreads uniformly on the disk with finite radius. We restrict ourselves into the subspace of the lowest Landau level.

First we show the result of numerical studies on the electron removal excitation for systems with six and seven electrons. The spectral function obtained by numerical diagonalization exhibits following two properties: (i) The spectrum is classified into two parts with respect to the intensity. The part with large intensity lies in the low energy side. (ii) There appear remarkable structures on the low energy bound of the spectrum. In order to analyze these properties of the spectrum, we introduce a variational wave function called "p-quasi-hole state" for the electron removal excitation in $\nu = 1/p$. Comparison of the single-electron spectral function with the energy spectrum of the p-quasi-hole state gives the interpretation on the properties of the single-electron spectrum in terms of the elementary excitation: (i) The region with large intensity almost coincides with the spectrum of p-quasi-hole states. This means that the electron removal excitation is approximately reproduced by p-quasi-hole excitation, in other words, the elementary excitation picture is valid. (ii) The structure on the low energy bound is well reproduced by the spectrum of the single quasi-hole. Therefore the low energy bound of the spectrum reflects the intrinsic nature of the quasi-hole directly and its shape provides the evidence of the quasi-hole excitation.

Next we discuss the single-electron spectrum for $\nu = 1/3$ in the macroscopic limit. To this end we obtain the spectrum of three-quasi-hole states in the macroscopic limit as follows. At the beginning, the spectrum is qualitatively expected by intuitive analyses of three-quasi-hole states. Secondly the expected spectrum is confirmed by numerical studies on the three hole excitation in $\nu = 1$ with $N = O(10^2)$ electrons and by the Monte-Carlo calculation on the excitation energy of three-quasi-hole states in $\nu = 1/3$ with $N = 11$ electrons. Furthermore, by Monte-Carlo method, we evaluate the excitation energies in the macroscopic limit with respect to four three-quasi-hole states, namely (1) three quasi-holes are at the edge, (2) one quasi-hole is at the center with the other two at the edge, (3) two quasi-holes are localized at the center with the other one at the edge, (4) all of the three quasi-holes are at the center. With these energies, the excitation spectrum of three-quasi-hole states is quantitatively obtained. Now the single-electron spectrum is composed of the spectrum of three-quasi-hole states and that of bound states of quasi-holes expressed by linear combinations of three-quasi-hole states. In particular, we show that free quasi-hole continuum gives rise to the iterative structure on the low energy bound of the single-electron spectrum. Such structure reflects the nature of the quasi-hole directly and thus signifies manifestation of fractionally charged quasi-hole excitation.