Localization-Delocalization Transition by Interactions in One-Dimensional Fermion Systems

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It is known that the randomness and the mutual interaction play essential roles in one-dimensional fermion systems. All states are Anderson-localized in the absence of interactions[1)], while interacitons in clean system introduce the divergence of various response functions as the temperature, T, is lowered.[2)] Thus it is interesting and important to understand the interplay between randomness and interaction, especially in one-dimension.

Luther and Peschel[3)] first examined the effect of impurity scattering on the Tomonaga model.[4)] The same problem has been treated later in more detail by Chui and Bray,[5)] and Apel.[6)] The former authors expanded the density autocorrelation function in perturbation series in the strength of impurity potential by relating the terms in the series to the partition function for a two-dimensional Coulomb gas, while the latter examined the dynamic conductivity by similar but different method. Both investigation resulted in the same critical value of the interaction constant for the transition between insulating and conducting states at T=0. The fermions interacting via spin-dependent backward scattering have been treated by Chui and Bray,[7)] and Apel and Rice.[8)] They found the existence of the critical values similarly, but their values are numerically different.

The present paper considers the same kind of problem. For this purpose we first propose a new way to treat the Anderson localization in the presence of impurity scattering based on the phase Hamiltonian defined by the bosonization of the fermion field. In terms of phase variables representing the charge and spin degrees of freedom the Anderson localization can be viewed as the pinning process of these phases by the impurity potential. This impurity pinning can be treated by the same technique as developed for the Peierls system.[9,10)] Next the spin-dependent Tomonaga model is considered in the same framework. In this model mutual interactions shown in Fig.1 is considered. The phase diagram of this model is exactly known in the clean system,[2)] i.e. the region in the plane of coupling constants is classified according to the types of most singular response fucntions of SS (singlet superconductivity), TS (triplet superconductivity), CDW (charge density wave) and SDW (spin density wave). This is shown in Fig.2. We determined the phase diagram of localization and delocalization in the same plane. The result is shown in Fig.3.

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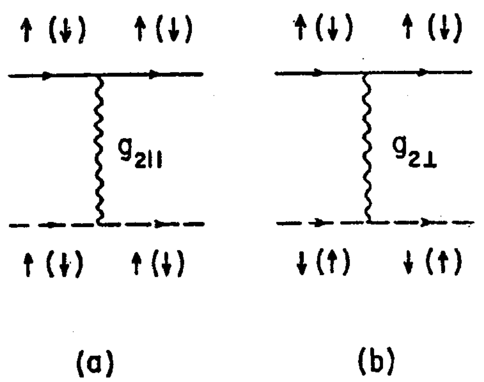

Fig.1 Interaction processes of forward scattering between parallel spins (a) and antiparallel spins (b).

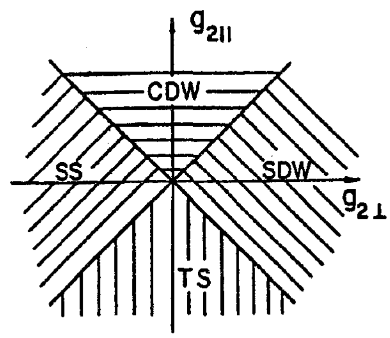

Fig.2 Phase diagram of the spin-dependent Tomonaga model in the clean system.

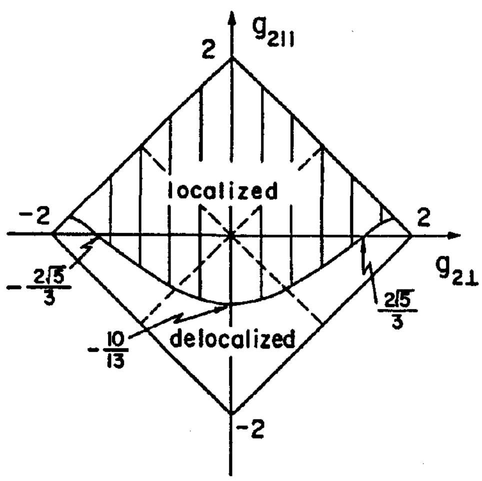

Fig.3 Localized and delocalized region on the plane of $g_{2\perp}$-$g_{2\parallel}$.

The broken lines denote the boundaries shown in Fig.2.