Low energy effective interaction of XXZ spin interaction on 2 dimensional quantum dot

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最近の実験により、$T=0$ でコンダクタンスのピークが有限の幅をもつような量子ドットが発見された。これを理論的に説明するため、繰り込み群の方法を用いて低エネルギー有効 Hamiltonian を求めた。その結果、universal Hamiltonian に向かう相 (fixed point) の他に、相互作用の揺らぎが大きくなる相 (fixed point) が現れ、特に、異方性の効果が重要であることがわかった。

In recent experiments of a quantum dot (QD) [1], it has been observed that conductance peaks retain finite widths even at very low temperature. Being motivated by this, we investigate the low-energy behavior of QD with anisotropic electron-electron interaction, which is expected to be residual such as in metallic ferromagnets. In particular, we examine how the anisotropic interaction may or may not stabilize various RG fixed points including the universal Hamiltonian.

We consider the two-dimensional QD. In the QD, the (effective) interaction between the i-th and j-th electrons is assumed to be

$$V_{ij} = \Phi_{ij} + J^x_{ij} S^x_i S^x_j + J^y_{ij} S^y_i S^y_j + J^z_{ij} S^z_i S^z_j,$$

where S^x, S^y, S^z are spin operators while Φ is the density part. We assume that the effective spin interaction may have the anisotropy of the XXZ type ($J^x = J^y$). As for the orbital part of the interaction ($\Phi_{ij}, J^x_{ij}, J^z_{ij}$), we consider the isotropic Fermi liquid channels on the two-dimensional plane.

The effect of the anisotropic interaction on the low-energy behavior is analyzed using the RG method incorporating the random matrix theory, as has been proposed by Murthy *et al.*[2]. As a result, it is found that the anisotropy gives rise to 8 phases (see Table 1). It is shown that the anisotropy makes the universal Hamiltonian unstable in certain parameter regions, and when it happens, the RG flow drives the system toward either the XY type or the Ising type. A rough sketch of phase boundaries is shown in Fig.1(a), where the horizontal axes $\tilde{u}^{11}_n$ and $\tilde{u}^{00}_n$ are the triplet and the singlet part of the interaction, and $C = \ln 2$. The plane (C) corresponds to the case of isotropic interaction, $\tilde{J}^z - \tilde{J}^x = 0$, on which the result of Ref. [2] is reproduced. On the planes (A)-(E) parallel with the isotropic plane (C), there exist a region (shown as shaded area in Fig.1(b)) where anisotropy drives the system unstable and the region gets larger with the

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	Φ	J^x	J^z	Preferred anisotropy
(1)	0	0	0	isotropic (Universal)
(2)	$-\infty$	0	0	isotropic
(3)	0	$-\infty$	0	XY
(4)	0	0	$-\infty$	Ising
(5)	$-\infty$	$-\infty$	0	XY
(6)	$-\infty$	0	$-\infty$	Ising
(7)	0	$-\infty$	$-\infty$	$\begin{cases} J^x < J^z < 0 \to \text{XY} \\ J^z < J^x < 0 \to \text{Ising} \end{cases}$
(8)	$-\infty$	$-\infty$	$-\infty$	$\begin{cases} J^x < J^z < 0 \to \text{XY} \\ J^z < J^x < 0 \to \text{Ising} \end{cases}$

Table 1: Eight types of possible RG flows.

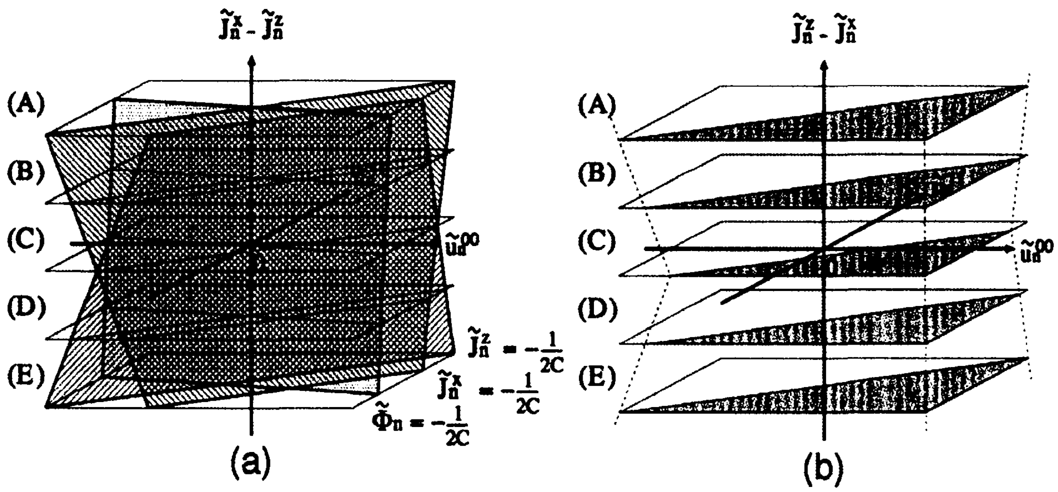

Figure 1: (a) shows three phase boundaries (shaded planes) of RG flows. (b) shows that unstable regions due to anisotropy (depicted by shaded area) get larger when the anisotropy increases.

increasing anisotropy.

The results show that the anisotropy effect can make the universal Hamiltonian unstable in very low temperature. The experiments [1] may have already captured such an instability or a crossover toward it.

References

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