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Thermal and Spatial Entanglement of Quantum Impurity Systems

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The quantum coherent screening of a local spin is an essential concept of quantum impurity problems. In this work, we theoretically analyze the quantum coherent screening by using quantum entanglement. We develop a method to compute the entanglement negativity between the impurity spin and electrons in spin-1/2 impurity problems, based on the boundary conformal field theory and numerical renormalization group [1]. We analyze thermal entanglement and its spatial profile, which is called the screening cloud, in multichannel Kondo systems [1,2] and two-impurity Kondo systems [3]. At low temperature, we show the universal behavior that the entanglement exhibits a power-law thermal decay with fractional exponent. The exponent is determined by the scaling dimension of the boundary operator representing the impurity spin. We show that the spatial distribution of entanglement also has the universal power law structure with the same exponent. We find that distinct (non-)Fermi liquids coexist in the distribution, forming concentric shells centered at the impurity. Outer shells are suppressed one by one as temperature increases, and the remaining outermost shell determines the entire phase of the system at that temperature.

[1] D. Kim, J. Shim, and H.-S. Sim, Phys. Rev. Lett. 127, 226801 (2021)
[2] J. Shim, D. Kim, and H.-S. Sim, Nat. Commun. 14, 3521 (2023).
[3] D. Kim, M. Kim, J. Shim, and H.-S. Sim, in preparation.

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