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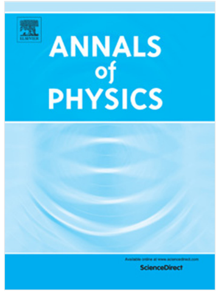

Residual entanglement of accelerated fermions is useful

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Residual Entanglement of Accelerated Fermions is Useful

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The non-vanishing residual entanglement, between the fermionic modes in the infinite acceleration limit, does not violate CHSH inequality, therefore it is not non-local. In this paper, we study the usefulness of the residual fermionic entanglement in single mode approximation and beyond single mode approximation. It is shown that there are some cases where the CHSH inequality is not violated by the residual entanglement, but the state is useful for quantum teleportation. Conditions for the violation of the CHSH inequality in terms of the "presence probability" of the particle in different Rindler regions are given for the state to be useful for teleportation and superdense coding.

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I. INTRODUCTION

Entanglement is very important in quantum information processing. In 1935 Einstein, Poldolsky and Rosen (EPR) by using an entangled state to be shared between the two particles, suggested that quantum mechanics is incomplete or is non-local [1]. Existence of some hidden variables could give rise to a complete description for the state measurement and dictates an inequality, called Bell inequality, on the measurements outcomes [2]. Violation of Bell inequality shows that a local realistic interpretation of quantum mechanics is impossible. In this regard, varieties of experiments to test the Bell inequality are devised [3].

Clauser-Horne-Shimony-Holt (CHSH) inequality [4], is an inequality in the class of Bell inequalities, that is suitable for bipartite systems. In a bipartite system, with the density matrix, ρ, shared between Alice, A, and Bob, B, (Rob, R, in accelerated scenario) e. g. measurements on orientations of polarizations or spin directions are characterized in the form of $\mathrm{A}_1(\lambda) = a_1.\sigma$, $\mathrm{A}_2(\lambda) = a_2.\sigma$, $\mathrm{B}_1(\lambda) = b_1.\sigma$, and $\mathrm{B}_2(\lambda) = b_2.\sigma$, where $\{a_1, a_2, b_1, b_2\}$ is a set of unit vectors. Then, CHSH operator is defined as follows

$$\mathcal{B} = a_1.\sigma \otimes (b_1 + b_2).\sigma + a_2.\sigma \otimes (b_1 - b_2).\sigma, \tag{1}$$

where σ is a vector of the Pauli matrices. The CHSH inequality is given by

$$|\mathrm{Tr}(\rho\mathcal{B})| \leq 2. \tag{2}$$

A 3×3 dimensional correlation tensor T_ρ is defined by the following elements

$$t_{ij} := \mathrm{Tr}[\rho(\sigma_i \otimes \sigma_j)], \tag{3}$$

where $i, j = 1, 2, 3$. The maximum possible average value for $\mathcal{B}$ is determined by optimizing the unit vectors a_1, a_2, b_1 and b_2 as follows

$$\mathcal{B}_{\max}(\rho) = \max_{\mathcal{B}} |\mathrm{Tr}(\rho\mathcal{B})| = 2\sqrt{\mathcal{M}(\rho)}, \tag{4}$$

$\mathcal{M}(\rho) = \lambda_1 + \lambda_2$. λ_1 and λ_2 are the two largest eigenvalues of the matrix $\mathcal{U}_\rho = T_\rho^T T_\rho$, and T_ρ^T is the transposed matrix of T_ρ. If $\mathcal{M}(\rho) > 1$ then the CHSH inequality is violated, [5]. CHSH inequality is violated on the condition that the state is entangled. On the contrary side, not all entangled states violate CHSH inequality [6].

Entanglement helps to transfer the information from Alice to Bob, in the original quantum teleportation scheme [7]. The initial state of the system for quantum teleportation is $|\psi\rangle_{in} = |\psi\rangle_a |\Phi^+\rangle_{\mathrm{AB}}$, where $|\psi\rangle_a = \alpha|0\rangle + \beta|1\rangle$ is the state to be teleported and $|\Phi^+\rangle_{\mathrm{AB}} = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$ is the shared entangled state. Alice performs measurement in Bell basis and sends the outcome ij to Bob. Bob applies unitary transformation $U_{ij} = \sigma_3^i \sigma_1^j$, where σ_3 and σ_1 are Pauli operators, and