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LETTER TO THE EDITOR

Polarization enhancement in $\vec{d}(\vec{p},\vec{n})^2$He reaction: nuclear teleportation

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Abstract

I show that an experimental technique used in nuclear physics may be successfully applied to quantum teleportation (QT) of spin states of massive matter. A *new* non-local physical effect, the 'quantum-teleportation effect', is discovered for the nuclear polarization measurement. Enhancement of the neutron polarization is expected in the proposed experiment for QT that discriminates *only* one of the Bell states.

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1. Introduction

The discovery of quantum teleportation (QT) [1] is one of the most profound results of quantum information theory. By means of a classical communication channel and a quantum source realized by a non-local entangled state such as an EPR-pair of particles, the teleportation process allows us to transmit an unknown quantum state from a sender to a receiver that are spatially separated. Experimental realizations of QT have so far been limited to teleportation of light rather than massive fermions [2, 3]. The present work gives an experimental scheme for the QT of proton spin to neutron spin in the $\vec{d}(\vec{p},\vec{n})^2$He reaction.

2. QT with $\vec{d}(\vec{p},\vec{n})^2$He reaction

Preparing a polarized $\vec{d}$ target ${}^3S_1$ and $m_s = 0$ state with polarized proton beam and selecting the knockout reaction, will lead to the QT of the beam polarization to the outgoing neutron. In fact, for clarity reasons two assumptions are made.

Assumption I. Assuming the initial states of the deuteron target and the proton beam are pure[1], the deuteron spin state could be written as

$$|\psi^+\rangle_{23} = \frac{1}{\sqrt{2}}(|01\rangle + |10\rangle) \qquad (1)$$

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[1] A general procedure of QT of mixed state through noisy channel could be found in [4].

Table 1. Special requirement for the QT experiment with $\vec{d}(\vec{p},\vec{n})^2$He reaction.

Target polarization	Beam polarization	Reaction type	Detection systems
$P_z \sim 0$ $P_{zz} \sim -2$	$a\|0\rangle + b\|1\rangle$	Knockout reaction	P_{neutron} E_{neutron}

and the proton spin state as

$$|\Phi\rangle_1 = a|0\rangle + b|1\rangle \tag{2}$$

where 1, 2, 3 denote the two protons, and the neutron states, respectively, and $|0\rangle, |1\rangle$ correspond to the positive, negative projection of the spin onto the quantization axis, respectively. Using the so-called Bell's basis such that

$$|\psi^{\pm}\rangle = \tfrac{1}{\sqrt{2}}(|01\rangle \pm |10\rangle) \qquad |\phi^{\pm}\rangle = \tfrac{1}{\sqrt{2}}(|00\rangle \pm |11\rangle) \tag{3}$$

the initial spin state of the system $(\vec{d}, \vec{p})$ could be written as follows:

$$\begin{aligned} |\Psi\rangle_{123} = {} & |\phi^{+}\rangle_{12} \otimes (a|1\rangle + b|0\rangle)_3 + |\phi^{-}\rangle_{12} \otimes (a|1\rangle - b|0\rangle)_3 \\ & + |\psi^{+}\rangle_{12} \otimes (a|0\rangle + b|1\rangle)_3 + |\psi^{-}\rangle_{12} \otimes (a|0\rangle - b|1\rangle)_3. \end{aligned} \tag{4}$$

Assumption II. Assume that the polarization transfer and the induced polarization at 0° are neglected for the knockout reaction. This assumption is supported by the low measured $K_y^{y'} \sim -0.1$ [5] of the reaction $1 + \vec{1}/2 \to \vec{1}/2 + 0$ that has the same spin structure of the $\vec{d}(\vec{p}, \vec{n})^2$ He reaction for the unpolarized d. This suggests that the $\vec{1} + \vec{1}/2 \to \vec{1}/2 + 0$ reaction will have low $K_y^{y'}$. Therefore, measuring the polarization of the high energy neutron, i.e. low pp relative energy will force the two outgoing proton states to be singlet and project the wavefunction of equation (4) after measurement onto [5]:

$$|\Psi\rangle_{123} = |\psi^{-}\rangle_{12} \otimes (a|0\rangle - b|1\rangle)_3. \tag{5}$$

Clearly, the polarization of the proton beam has been teleported to the outgoing neutron polarization. By a 180° rotation around the y direction the state of the proton beam will be recovered by the outgoing neutron. Note that this experiment is not complete teleportation because we discriminate only the $|\psi^{-}\rangle$ state[2]. If the teleportation is taking place in such a reaction a strong correlation should be observed between the polarization of the outgoing neutron and the polarization of the proton beam. Specially, when the polarization of the beam is in the x direction the expected polarization of the outgoing neutron is in the $-x$ direction (flipped). However, for the y polarization no flipping should be observed. Special requirements of the experiment are listed in table 1.

3. Conclusion

I have shown that the teleportation of massive fermions could be implemented using the available experimental technique. I have suggested a new physical effect for the nuclear polarization measurement namely the 'quantum-teleportation effect'. For the proposed experiment the expected neutron polarization is more or less zero, however taking into account

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[2] The contamination from higher multipole is estimated to be 4% and it is neglected here.

such an effect the neutron polarization should be enhanced and strongly correlated with the beam polarization. A dynamical study that couples the quantum entanglement with the nuclear decoherence due to the polarization transfer and the induced polarization will be addressed elsewhere.

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