J. At. Mol. Sci.
doi: 10.4208/jams.011310.042910a

Vol. **2**, No. 1, pp. 81-92
February 2011

Implementations for remotely preparing single- and two-particle states in a four-level system

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Received 13 January 2010; Accepted (in revised version) 29 April 2010; Published Online 17 January 2011

Abstract. We propose two schemes to realize remote state preparation (RSP). The first scheme is designed to prepare an arbitrary single-particle state in a four-level system with the aid of one bipartite maximally entangled channel, which is then generalized to the second scheme, i.e., RSP for a two-particle state in a four-level system. During the two preparations, one single-particle projective measurement and one two-particle projective measurement are performed respectively. Our results show that the preparation for single-particle or two-particle states can be remotely realized with at least 25% successful probability and unit fidelity. Furthermore, with respect to two special ensembles of the prepared states, i.e., real and equatorial-like, the successful probability can be pushed up to 100%. Hence our probabilistic schemes become deterministic ones.

PACS: 03.67.Hk; 03.67.-a; 03.65.-w

Key words: remote state preparation, four-level system, projective measurement, successful probability

1 Introduction

Quantum entanglement brings on an amazing application in quantum computation and information, namely, quantum teleportation (QT). As we know, QT was originally presented by Bennett *et al*. [1] in 1993, and essentially plays a central role in quantum-information processing [2–9]. QT is used to taking on a task of transmitting an unknown quantum state from a sender (say, Alice) to a distant receiver (say, Bob) with the assistance of quantum and classical resources. Being very similar to QT, remote state preparation (RSP) firstly proposed by Lo [10] is also devoted to remote transmission for quantum states, and is usually reckoned as "teleporting a known state". As a matter of fact, both of them require the help

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of quantum entanglement set up previously and classical information communication. The two creative and promising methods of quantum-information processing in essence reveal the interchangeability of different resources in quantum mechanics. Nevertheless, there are a few remarkable differences between QT and RSP as follows: (i) in QT, whether the sender knows the quantum state to be teleported is disregarded at all. Contrarily, the preparer of the state is entirely aware of the state to be prepared in RSP; (ii) The state to be delivered initially inhabits concrete particles in QT, while this never takes place in QT; (iii) Classical communication cost (CCC) needed in QT is different from that in RSP. Bennett *et al.* [11] have showed that the asymptotic classical communication cost of RSP is one bit per qubit-half that of teleportation. Nonetheless, noteworthily, its price is that the success probability (SP) of state preparation is less than one (probabilistic), but that of teleporting a state can reach one in QT (deterministic). Furthermore, the RSP protocol presented by Pati [12] showed that it requires only one classical bit (cbit) for conclusively preparing a single-qubit state chosen from equatorial or polar great circles on a Bloch sphere, while in standard teleportation two cbits are indispensable. In this sense, RSP is more economical than QT for the special states. Afterward, enlighten by those pioneering works [8–10], many authors concentrate on RSP so much, and have already put forward a large number of RSP proposals [13–29]. Such as, the low-entanglement RSP [13], the optimal RSP [14], the oblivious RSP [15], the RSP without oblivious conditions [16], the generalized RSP [17], the faithful RSP [18], the RSP for multi-parties [19], the joint RSP [20], the RSP for qubit states [21–24], the RSP for qutrit states [25] and the continuous variable RSP in phase space [26] have been presented theoretically. On the other hand, some RSP schemes have already been realized experimentally [27–32], e.g., Peng *et al.* presented a RSP scheme with the technique of NMR (nuclear magnetic resonance) [27], Xiang *et al.* [28] and Peters *et al.* [29] proposed other two RSP schemes using spontaneous parametric down-conversion.

The multilevel quantum systems are promised to be more compact and efficient in both coding and manipulating quantum information [33]. To our knowledge, recently, teleportation for multipartite and multilevel quantum states have been investigated extensively. By contrast, up to now there just have existed a few schemes [34, 35] for implementing RSP in multi-level systems. In fact, Refs. [34, 35] care more on RSP of qudit states in real Hilbert space and the equatorial qudits, and neither of which has investigated RSP of the ensembles of qudits in complex space. As a result, both of them cannot be readily generalized to the case for RSP of an arbitrary single-particle state. Alternatively, we firstly propose such a scheme, which is used for realizing the RSP for a single-particle state in a four-level system, and then generalize to the case of a two-particle state. In the former, we employ one bipartite maximally entangled state as quantum channel. During the preparation, it is required to carry out one single-particle projective measurement and one appropriate unitary operation. In the latter, two bipartite maximally entangled states are taken as quantum channel, and one two-particle projective measurement and one appropriate unitary operation are performed for the preparation. Generally speaking, the two RSP schemes can be faithfully achieved with the same SP as at least 25%. Furthermore, we find the SP can be increased to 100% in the case of two special ensembles. One will see this later.