Quantum Fisher Information and Entanglement

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Recent advancements in quantum science made possible to think about utilizing quantum systems for development of various quantum sensors, such as clocks, gyroscopes, and accelerometers. Precision of a quantum sensor is defined by a number of quantum systems utilized for a measurement as well as by the correlations created between these systems. A sensor consistent from an ensemble of N uncorrelated atoms provides the precision scaling known as the standard quantum limit (SQL). Creation of highly correlated states (entanglement) of an ensemble of quantum systems is a key element for precision measurement improvement when the sensor precision is restricted by the Heisenberg limit (HL), which scales as the number of atoms N in contrast to the SQL scaling as $N^{1/2}$. Various quantum correlated states of atoms, such as spin squeezed states and Dicke states, allow to achieve scaling beyond the SQL, ultimately reaching the HL scaling. A simplified proposal to generate spin squeezed and Dicke states is based on engineering an effective atom-atom interaction, described by a one-axis twisting (OAT) Hamilton. In this work, using the unique energy level structure of the OAT Hamiltonian and applying standard rotations, we developed the rapid adiabatic passage control scheme to generate different classes of metrologically useful entangled states. To quantify the capacity of the entangled states for quantum metrology, we evaluate the quantum Fisher information which defines ultimate precision of the measurements. Our method permits to drive Dicke states of the many-atom system into entangled states with maximum quantum Fisher information. The designed states allow to overcome the classical limit of phase sensitivity in quantum metrology and sensing. We discuss how to generate superpositions of Dicke states, which maximize metrological gain for a Ramsey interferometric measurement. The proposed scheme is remarkably robust to variations of the driving field and has favorable time scaling, especially for small to moderate (~10000) number of atoms, where the total time does not depend on the number of atoms.