Probing Quantum Discord in a Heisenberg Dimer Compound

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Abstract

Quantum correlations between the microscopic constituents of a solid state system could affect its macroscopic thermodynamic properties. As an example, for a magnetic system comprising spin ½ particles arranged in a lattice, magnetic susceptibility is capable to reveal spin entanglement between its constituents [1]. Thus a Fruitful link has been established between quantum mechanics and thermodynamics and one can encapsulate information about entanglement by only carrying out basic thermal and magnetic measurements. Based on this criterion, quantification of quantum correlations (quantum discord, Total correlations and spin-spin pair correlation) and violation of Bell's inequality test is performed from experimental magnetic susceptibility and specific heat data for a Heisenberg spin ½ dimer compound.

Entanglement does not account for the total "quantumness" present in the system. In fact, it was observed that there are certain quantum mechanical phenomena [2, 3] which cannot be explained with the knowledge of entanglement. In order to address this issue, a new quantity called Quantum Discord has been introduced [4] which by definition captures the "non-classicality" that encompasses entanglement as a subset [5]. Quantum discord has been recognized as a valuable resource as it encompasses a wider region in the quantum domain and witnesses non-classical correlations also in the separable phase of a correlated quantum system.

Quantum clusters have been recognized as an ideal playground for studying quantum correlations [6]. In addition to entanglement study, considerable amount of research works have been undertaken in investigating QD in the ground state and in the thermal states of interacting spin systems. The present work deals with the detection of Quantum discord as a function of temperature in NH_4CuPO_4, H_2O [7]. NH_4CuPO_4, H_2O can indeed be described by isolated spin 1/2 Heisenberg dimer model and studied in the present work from the perspective of quantum information science. Such an effective two qubit system (dimer) has finite (4-dimensional) Hilbert space and has a spin gap, with the magnitude of the gap being the energy difference between the singlet and triplet levels. QD has been determined for such a 2-qubit spin gapped system experimentally from magnetic susceptibility and specific heat data. Thus, macroscopic thermodynamic properties of a solid state bulk body are connected with the quantum mechanical correlations between its microscopic constituents. Total correlations (I) and spin-spin pair correlation (G) were also calculated from the experimental data and their variations are captured as a function of temperature. It has been observed that, at lowest temperature QD, I and |G| are at their maximum values of one. As temperature is increased, the decaying nature of all the three correlations is captured.

Numerous different propositions have been made for the quantification entanglement from macroscopic observables [6]. Amongst them, violation of Bell's inequality test has been established as an efficient tool to determine the presence of entanglement mainly due to its fundamental significance in foundation of quantum mechanics. Herein, macroscopic thermodynamical quantities, namely, magnetic susceptibility and internal energy have been used to perform Bell's inequality test for the same compound. The mean value of the Bell operator is quantified and plotted as a function of temperature. The threshold temperature is determined above which the Bell's inequality is not violated and a very good analogy between magnetic susceptibility and specific data have been observed in this regard. Hence, for a real physical system, a Bell measurement combined with quantification of QD allows us to make the decisive statement that QD can survive persistently even in the region where Bell's inequality is not violated.

References

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