Present status of the programme of Hidden Variable Theory and its implications

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Abstract. Hidden Variable Theory (HVT) is a programme to replace quantum mechanics by a relatively more complete theory which is expected to respect our general notion of reality. Bell and Kochen-Specker, for the first time, shattered that dream for some classes of Hidden Variable Theory. Very recently there are some results which claim to have rejected the whole class of HVT where quantum state is not a part of the reality of the physical system. We discuss this development along with some new result regarding a connection between GHJW theorem and nonlocality in all HVT theories. Along with these we also discuss a recently suggested two-party game which, for the first time, presents some operational criteria to separate entangled states from separable states.

Keywords: Hidden Variable Theory, ontological model, epistemic model, nonlocality, contextuality

Since the inception of quantum mechanics, there had existed the dream of replacing quantum mechanics by a complete theory which would respect the common sense notion of reality [1, 2]. Bell [3] and Kochen Specker [4], for the first time, shattered that dream for some classes of Hidden Variable Theory (HVT). It was shown that no realistic theory which respects twin assumptions of locality and contextuality, cannot reproduce all results of quantum mechanics. These results not only sharpen the points in the philosophical debates among physicists and philosophers, they have also found important applications. Though quantum mechanics respects no signaling condition, this does not reduce the nonlocal feature to be not trivial. Specially, the power of quantum nonlocality is clearly manifested through various pseudo-telepathy games suggested recently. One of these games namely the Kochen-Specker game [5] can also be interpreted as a simple proof of impossibility of reproducing quantum correlation even by contextual local theory. The nonlocality of quantum mechanics finds its applications in distributed computing, secret key generation etc. This is one part of the story.

Another part of the story revolves around the question whether quantum state is necessarily part of the reality of physical system in the framework of complete or relatively more complete theory. The various HVT model proposed to replace either quantum theory or quantum theory for particular system, can be classified in two groups [6, 7]. One is called ψ - ontic where the quantum state is also part of the reality i.e. property of the system. Importantly there is an alternative model of quantum theory namely Bohm model which is nonlocal and contextual and it is ψ-ontic. The other group consist of models which are called ψ-epistemic and these models relegate quantum states to the position of information about ontological states i.e. it merely represents probability distribution over actual ontic states (Kochen-Specker model for qubit). There are some recent results which claim that ψ-epistemic model is in contradiction with quantum results [8, 9]. Of course, once the underlying assumption of preparation independence to derive this result is given up, one can again construct ψ-epistemic theory. Anyway, this result has generated an intense discussion among physicists [10].

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The non-locality of ψ-ontic model easily follows from steerability in EPR kind of example i.e. without invoking Bell like inequality which involves measurement statistics. Recently the non-locality of non-maximally ψ-epistemic model has been revealed by using singlet in the same fashion [11]. Subsequently it has also been shown that nonlocality of all bipartite pure entangled state can be established by using preparation contextuality and GHJW theorem for any ψ-epistemic model [12].

Another important thing that has attracted great attraction, recently, is why violation of Bell-CHSH inequality by quantum statistics remains much lower than that allowed by no signaling condition. Some suggestions motivated from quantum mechanics have appeared. It has been shown that Heisenberg uncertainty principle and Bohrs complementarity principle defined for single system reproduce quantum nonlocality limited by Chirelsons bound [13, 14]. But interestingly a principle of universal nature namely information causality principle has been suggested which also reproduces the Chirelsons bound [15].

Finally, though nonlocality is only manifested by entangled state in quantum mechanics, the nonlocal features could not draw a boundary line between entangled states and separable states as there are entangled states which are local with respect to all possible quantum measurements. Recently, a new type of game, namely semi-quantum game (where the inputs or questions are associated with quantum state) has been suggested which, for the first time, provides an operational criteria to separate entangled states from the set of separable states [16, 17].

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