Philosophy and Interpretations of Quantum Non-Locality

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Abstract

In this brief paper, we argue about some epistemological positions about quantum non-locality.

1 Interpretations of Non-Locality

Some theoreticians argue that nonlocality has a role in interpreting quantum phenomena. Others suggest that quantum nonlocality may be interpreted as a holistic, nonseparable relational issue.
Summarizing Einstein's famous objection to entanglement, in the EPR paper, Richard Healey (Healey, 1989)reminds us that he assumed a classical physics understanding of the state of a whole system as combining individual component states, not adding something. Fifty years after EPR, Howard (Howard, 2007) equivalently restates the EPR principle as "The real state of the pair AB consists precisely of the real state of A and the real state of B, which states have nothing in to do with one another". In this EPR-like perspective, there is no supervenience of the whole system upon its components. Because the EPR deduction of nonlocal entanglement implies supervenience and contradicts separability, the paper argued that some unknowns (Bohm's "hidden variables") are missing in QM. Healey finds convincing explanations of quantum nonlocality as either "metaphysical property holism" or

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"spatiotemporal nonseparability." The former implies that an entangled system is more than the sum of its parts. As EPR stressed, the whole (quantum state) seems to determine values of some of its parts. This threat to state separability was "one reason why Einstein denied that a QS's real state is given by its quantum state. This leads, according to Healey, to "physical property holism." The composite determines the state of its components.

In Healey's view, "nonseparability" can be interpreted as possibly varying magnetic field values extending "between" theoretically separated points in spacetime. And, he notes that yet-to-be-proven string theory does not eliminate the quantum non-separability problem. Esfeld (Esfeld 2004) develops a metaphysical interpretation of physical relations which significantly diminishes or eliminates a role for intrinsic properties in QM. For Esfeld, QM presents us with two alternatives:

> either physical phenomenon have unknown intrinsic properties or they are only relations. QM inclines us to the second view. "Quantum theory supports metaphysics of relations by speaking against intrinsic properties on which the relations [...] supervene.

Esfeld proposes a "metaphysics of relations that dismisses intrinsic properties of relata which are a supervenience basis for the relations." He points to Wheeler's "geometrodynamics" (1962) which described everything as configurations of the "four-dimensional continuum." Although, as Esfeld notes, Wheeler's scheme was later rejected as incomplete, it does demonstrate that we can have a relational model of objects such as particles and quantum states "without intrinsic properties."

A few theoreticians suggest that there is no space between apparently separated entangled particles. For example, Brian Greene (Greene, 2005) notes that:

> space cannot be thought of as [...] intervening space[....] (distance) does not ensure that two objects are separate [.. .][because of] entanglement.

Karakostas (Karakostas, 2006) interprets quantum nonlocality holistically. Although quantum level interaction produces entanglement, entanglement itself does not require interaction. According Karakistas, entanglement:

> does occur in the absence of any interactions [...] entangled correlations among the states of various physical systems do not acquire the status of a causally dependent relation [...] their delineation is rather determined by the entangled quantum state itself which refers directly to the whole system. [This is] a genuine quantum mechanical instance of holism: there exist properties of entangled quantum systems which [...] characterize the whole

> system but are neither reducible to nor implied by or causally dependent on the local properties of its parts.

The parts of an entangled system depend upon the whole rather than the reverse. Karakostas additionally argues that:

> physical systems are realized as context-dependent. Quantum entities are not "things-in-themselves." Their wholeness is mind-independent and "veiled" from perception. "Any discussion concerning [...] whole is necessarily [...] ontological, metaphysical[...] the only confirmatory element about it [is] the network of interrelations which connect its events.

Richard Healey finds that nonlocal entangled systems can be interpreted holistically:

> When one performs measurements of spin or polarization on certain separated quantum systems. The results ... exhibit patterns of statistical correlation that resist traditional causal explanation.

These correlations suggest "spatiotemporal non-separability.

Berkovitz-Hemmo (Berkovitz-Hemmo,2005)argue that quantum phenomena can be interpreted from a "relational modal" perspective. They claim that this point of view enables them to "solve the measurement problem and [...] reconciles QM with the special theory of relativity." In the process, they reject local properties and argue that entities should be viewed in terms of relations. The assumption of a local property was basic to the EPR argument for QM incompleteness. Esfeld argues that QE necessitates relational descriptions. The empirical verification of entanglement (for example, Aspect, 1982) means that there are no individual intrinsic properties of entangled particles, instead there are "only correlations between the conditional probability distributions of the state-dependent properties of the quantum systems." In addition, the relation of hidden variables to the components of an entangled system "requires intrinsic properties on which these correlations supervene. Relational quantum mechanics (RQM) restates several basic QM principles. From an RQM perspective, a statement about a quantum event such as "A has a value x" must be rephrased as "A has the value x for B." By itself, "A has a value x" is meaningless. Discussing the impact of Bell's Inequalities on a hidden variables interpretation, Esfeld finds that "Bell's theorem does not rule out hidden variables that satisfy separability[....] If (we postulate) hidden variables that establish a causal connection with any of these [explanations: superluminal, backwards

causation, or a joint cause], then [these] hidden variables [...] provide for intrinsic properties which are a supervenience basis for the correlations Esfeld finds that David Mermin's interpretation of QM which presents a "world of correlations without describing intrinsic properties of the correlate" is reasonable but unempirical. Instead, Esfeld finally argues that we must accept the empirically given evidence of QM and not expect additional factors. Filk (Filk, 2006) tries to avoid the nonlocal implications of Bell's Inequalities and finds "hidden variable" explanations feasible. Arguing that QM entanglement may be interpreted as local, he points out that "the wave function itself is interpreted as encoding the 'nearest neighbor' local relations between a QS and spatial points." This means that spatial position is "a purely relational concept[...] a new perspective onto quantum mechanical formalism where many weird aspects, like particle-wave duality, nonlocality of entanglement, and the 'mystery' of the double-slit experiment, disappear. This perspective circumvents the restrictions set by Bell's inequalities [...] a possible (realistic) hidden variable theory based on these concepts can be local and at the same time reproduce the results of QM "
Similarly, we could say that accurate probabilistic predictions of measurement results for an entangled pair can be made without specifying the separating distance between the members of the pair. Focusing on the relations between the members of the pair, enables us to more acceptably express a hidden variable explanation for the now-local entanglement phenomena. This non-spatial or a-spatial perspective can be seen in another relational approach to quantum theory explained by Rovelli (Rovelli, 1998) and Laudisa (Laudisa, 2004) and as one that "discards the notions of absolute state of a system, absolute value of its physical quantities, or absolute event[s] [...] [and] describes [...] the way systems affect each other [...] in physical interactions. The physical content of quantum theory is [...] the net of relations connecting all different physical systems. Bitbol (Bitbol, 1998)suggests that these theories could be naturalistic if they focus on relations as the collective probabilistic prediction several physical observers. However these relational QM views are held by a minority. Conventional interpretations (e.g., Copenhagen) of quantum theory accepted the predictions of EPR and welcomed the probabilistic verification of nonlocality in Bell's theorem. However, their explanations for QM nonlocality vary:

- Nonlocality is an integral feature of QM.
- Nonlocality indicates geometric relational acausality
- Nonlocal effects are atemporal

- Apparently nonlocal events are actually local
- There are superluminal causal links
- Nonlocal quantum events are relations between causal processes.

Each approach attempts to resolve philosophic questions raised by QM nonlocality. Some of these views are summarized above.

Nonlocality is Integral to Quantum Reality

Many theoreticians assume that entanglement involves no "hidden variables" and there are no undetected connections (e.g., no Bohmian "pilot wave") between distantly entangled particles." Bohr, Heisenberg, and many others accepted the predictions of EPR as consistent with QM.

Nonlocal Events are Atemporal

Recent articles by Suarez (Suarez, 2003, 2007) and others at the Center for Quantum Philosophy in Zurich (articles published in the Physical Letters) suggest that nonlocality necessitates timelessness. "Experiments with moving beam-splitters demonstrate that there is no real time ordering behind the nonlocal correlations. In Bell's world there is no 'before' or 'after.'" A few suggest that measurement notifications travel instantly across distances separating entangled particles. Entangled particles can be subject to a superluminal causal link. According to Ray-Murray, "It may be possible to avoid the [EPR] paradoxes [...] while accepting the existence of superluminal causal links [...] because we have no real control over the links. We cannot, for instance, use them to send superluminal signals of any kind." Mauldin (Rutgers University) also finds that "Superluminal signals must[...] propagate into the past: the signal is received before it is sent. The conditions required for the possibility of such paradoxes are more complex than merely the existence of superluminal signals. Accordingly, violations of Bell's inequality predicted by QM do not allow superluminal signals. [However] even though nature may not allow superluminal signally, it does employ, according to Bell, superluminal causation [...] this will pressure us to add more structure to space-time than Relativity says there is." Here, relativity theory is not challenged because no signal passes between the separated, entangled particles. However, Barbour interprets Aspect's experimental results as evidence of superluminal, causal contact. But a deeply troubled John Bell wrote the verified superluminal causal effect of nonlocal entanglement was "for me[.. .]the real problem of quantum theory.

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