A time-symmetrical formulation of quantum entanglement resolves paradoxical aspects of the conventional formulation (https://arxiv.org/abs/2003.07183)

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Abstract. I numerically simulate and compare the entanglement of two quanta using the conventional formulation of quantum mechanics and a time-symmetrical formulation that has no collapse postulate. The experimental predictions of the two formulations are identical, but the entanglement predictions are significantly different. The time-symmetrical formulation reveals an experimentally testable discrepancy in the original quantum analysis of the Hanbury Brown–Twiss experiment, suggests solutions to some parts of the nonlocality and measurement problems, explains quantum steering into the past, fixes known time asymmetries in the conventional formulation, and answers Bell's question "How do you convert an 'and' into an 'or'?"

Keywords: entanglement, numerical simulation, time-symmetrical, retrocausal

Quantum entanglement is at the heart of both new quantum information technologies [1] and old paradoxes in the foundations of quantum mechanics [2]. Despite significant effort, a comprehensive understanding of quantum entanglement remains elusive [3]. In this paper I compare how the entanglement of two quanta is explained by the conventional formulation of quantum mechanics [4] and by a time-symmetrical formulation that has no collapse postulate. The time-symmetrical formulation and its numerical simulations can facilitate the development of new insights and physical intuition about entanglement. There is also always the hope that a different point of view will inspire new ideas for furthering our understanding of quantum behavior.

Time-symmetrical explanations of quantum behavior predate the discovery of the Schroedinger equation [5], and have been developed many times over the past century [6]. The particular time-symmetrical formulation described in this paper is a type IIB model, in the classification system of Wharton and Argaman [7]. It is called time-symmetrical because (for symmetrical boundary conditions) the complex transition amplitude densities (defined below) are the same under a 180 degree rotation about the symmetry axes perpendicular to the time axes. The conventional formulation does not have this symmetry. To the best of my knowledge, this is the first quantitative explanation of entanglement by a time-symmetrical formulation. The closest work appears to be [8].

Identical quanta have the same intrinsic physical properties, e.g. mass, electric charge, and spin. But identical quanta are not necessarily indistinguishable: an electron in your finger and an electron in a rock on the moon are distinguishable by their location. Identical quanta can become indistinguishable when their wavefunctions overlap such that it becomes impossible, even in principle, to tell them apart.

Entanglement is usually taught using spin or polarization degrees of freedom. But entanglement also occurs in the spatial wavefunctions of systems with more than one degree of freedom [9]. For one quantum in two or more dimensions, two different parts of the spatial wavefunction can be entangled with each other, resulting in spatial amplitude interference, as in Young's double-slit experiment. For two quanta in one or more dimensions, the spatial wavefunctions of the two quanta can be entangled with each other, resulting in spatial intensity interference, as in the Hanbury Brown–Twiss effect [10].

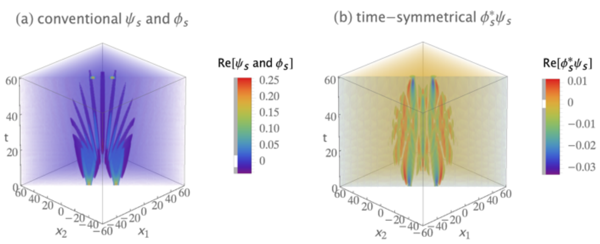

Figure 5 *(a) The conventional explanation of a Gedankenexperiment with two indistinguishable bosons: the symmetrized two-quanta wavefunction ψ_s is emitted by sources S_a at $(x_a,t_i)=(10,0)$ and S_b at $(x_b,t_i)=(-10,0)$, evolves in time, then abruptly collapses onto the symmetrized two-quanta wavefunction ϕ_s and is absorbed by detectors D_c at $(x_c,t_f)=(7,60)$ and D_d at $(x_d,t_f)=(-7,60)$. The conventional formulation assumes the two-quanta wavefunction is a 2-dimensional object which lives in configuration space, evolves in time, and gives the most complete description of the two quanta that is in principle possible.*

(b) The time-symmetrical explanation of the same Gedankenexperiment: the symmetrized two-quanta transition amplitude density $\phi^\ast_s\psi_s$ (where $\phi^\ast_s$ is the complex conjugate of the ϕ_s in the conventional explanation) is emitted by sources S_a and S_b, and the quanta are absorbed by detectors D_c and D_d. There is no abrupt collapse. The time-symmetrical formulation assumes the symmetrized complex transition amplitude density is a (2+1)-dimensional object which lives in configuration spacetime and gives the most complete description of the two quanta that is in principle possible. The transition amplitude density $\phi^\ast\psi$ is normalized to give a transition probability of one, only the real parts of ψ, ϕ, and $\phi^\ast\psi$ are shown, and half of the plots are cut away to show the interiors.

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