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Resolution of The Quantum Clock-Time Observable

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Time is perhaps the most enigmatic concept in physics [1]. Indeed, we still lack an acceptable explanation for the observed preferred direction of time, and a universally-accepted quantum treatment of time as an observable [2 - 4]. The observations of discrete symmetry violations of charge conjugation (⊠), parity inversion (⊠), and time reversal (⊠) observed in high energy particle decays, have further complicated our understanding of nature [5]. Such discrete symmetry violations have been observed independent of position, and so occur over translations in time [6].

The recently introduced Quantum Theory of Time (QTT) [6] describes the evolution of a quantum state over time as a variable, undergoing virtual displacement, with translations generated by the Hamiltonian. The theory attributes the differences between the spatial and temporal dimensions to the violation of the time reversal symmetry. As a result of the asymmetry in the evolution of time, imposed by T-violation, the two unique Hamiltonians Ĥ⊠ and Ĥ⊠, representing the forward and backward directions of time, respectfully, maintain a non-zero commutator mediated by the effective strength of the local T-violation ⊠ = ⊠ 〈[Ĥ⊠ , Ĥ⊠]. This implies that the time shown by an accurate clock depends on the value of ⊠ in its local region. If there is no T-violation present, the spatially-averaged time is fixed at one value and so there is no time evolution. However, with T-violation in the system, time is represented as fluctuating at every point in space about a spatially-averaged time that corresponds to the usual time evolution. Although QTT describes the change in the state of clock, it has not yet been applied directly to an operator that represents observable time, i.e. clock-time. The aim of this work is to investigate how the expectation value of a clock-time observable changes in time and determine the expected statistics of a clock, within QTT. For consistency with QTT, any time observable needs to have a canonically conjugate relationship with the Hamiltonian, due to the fact that the Hamiltonian is the generator of translations in time. We examine the complement of the Hamiltonian, Pegg's Age operator [4], as a basis for defining the time observable. In QTT, a clock is represented as a composite system entangled with a T-violating background field, as an extension of Page and Wooters'relational time [7]. Pegg defined the Age to represent time associated with changes in an arbitrary system. Age can be utilised in QTT to define the time associated with a clock-time observable. Here we apply the Age operator to explore the time-energy uncertainty relation for clock-time and the potential correlation of clock-time with temporal fluctuations in the T-violating background field. We further examine the relationship of the observable to conventional studies of time in quantum mechanics such as the time associated with time-of-flight measurement [8].

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