The EPR correlation in Kerr-Newman spacetime

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The EPR correlation has become an integral part of quantum communications as has general relativity in classical communication theory, however when combined an apparent deterioration is observed for spin states. We consider appropriate changes in directions of measurement to exploit full EPR entanglement for a pair of particles and show that it can be deduced only up to the outer even horizon of a Kerr-Newman black hole, even in the case of freely falling observer.

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I. INTRODUCTION

For some of the founders of quantum mechanics one of the troubling parts was the spooky action-at-a-distance. Originally this was thought up by Einstein-Podolsky-Rosen (EPR) in an attempt to challenge certain aspects of quantum theory at the time. Contrary to its original design it is now the cornerstone of modern mainstream quantum physics, from cryptography to quantum computation, thus it is important to understand as many of the properties of quantum communications as possible. In particular it is of importance to fully understand the effect of spacetime curvature on EPR states. This is completely different from classical information transport. In this scenario the space between observer and emitter does not have an effect on the transmission which means that only local spacetime effects matter when making measurements on transmissions.

In this paper, we apply the Terashima and Ueda [1] approach to the spacetime background of a Kerr-Newman black hole. In general relativity the spin of a particle becomes deformed in all but the Minkowski spacetime. We present a method to extract the complete EPR correlation of two particles in a Bell state in Kerr-Newman geometry, ignoring helicity of infalling particles. These particles are defined locally and so suffer a precession of their spin component due an acceleration by an external force and the difference in the local inertial frame at different points about the given geometry. Taking these differences to arise from a continuous succession of local Lorentz transformations (LLT), the spin component can be calculated since it precesses in accord with the Wigner rotation. It is therefore not a trivial task to describe the motion of a particle using quantum mechanics near a Kerr-Newman black hole because the Poincaré group does not act intuitively in this region.

This paper is organized as follows, in Sec. II we derive the spin precession in the Kerr-Newman background for an observer at infinity. Then in Sec. III we consider the EPR correlation for a pair of fully entangled particles. In an attempt to remove the coordinate singularities from the derived angle we then calculate the spin precession for an infalling observer in Sec. IV. In Sec. V we discuss Bell's inequality for the observers at infinity and the infalling observer. Finally in Sec. VI we summarize our results.

II. KERR-NEWMAN DISTORTION

The most general vacuum solution of Einstein's field equations for black holes is the Kerr-Newman metric, any further complications requires one to consider hairy black holes. In this paper we take the Minkowski signature to be $\eta = \mathrm{diag}(-,+,+,+)$ and use geometric units ($G = 1 = c$). Latin letters are run over the four inertial labels (0,1,2,3) and Greek letters over the four general coordinate labels. Also repeated indices are to be summed. Then the metric for the Kerr-Newman spacetime in *Boyer-Lindquist coordinates* (t, r, θ, ϕ) for an observer at infinity is given by