Wave propagation in a generalized Minkowski space and superluminal signals

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ABSTRACT. Tunnelling of wavepackets at velocities higher than the light speed in vacuum finds a natural explanation in the framework of a generalization of special relativity, in which nonlocal interactions are described in an effective way by means of a deformation of the usual Minkowski metric. This picture can be considered as an effective description of "virtual" particles (propagating with imaginary "classical" wavevector in the usual spacetime) as objects which propagate in the deformed Minkowski space with a "new", but real, wavevector. Our formalism is explicity applied to the superluminal propagation of electromagnetic evanescent waves in waveguides. We propose also an experimental setup, based on light propagation in optical fibers, which may provide a new optical test of e.m. superluminal tunneling.

1 - Introduction

The problem of the range of validity of the usual special Relativity (SR), based on the pseudo - Euclidean Minkowski space and its related Lorentz group of transformations, is, as well known, a much debated question since a long time.

Although generalizations of SR have been considered also at a large-scale level (in order e.g. to account for the existence of the preferred reference frame represented by the relic background radiation), the most interesting issue seems to be the modification of SR at high energies and/or at small distances, in order to overcome the difficulties encountered in recounciling SR and quantum mechanics[(1)].

In this connection, in the last years an extension of special Relativity has been developed[(2,3)], essentially aimed to describe, in an effective way, interactions structurally more general than the usual (local and derivable from a potential) ones. Such a formalism was named "deformed Special Relativity" (DSR), because basically based on a "deformation" of the usual Minkowski metric. Among the others, the DSR predicts a deviation of the particle lifetime from the usual Einsteinian behaviour[(3,4)], and permits to accomodate in a natural way the existence of superluminal causal speeds. Moreover, it is also able to account for possible nonlocal effects in electromagnetic interactions.

In this paper, we want to investigate the problem of wave propagation in the deformed Minkowski spacetime of DSR. As we shall see, the tunnelling of wavepackets at speeds higher than the light speed in vacum finds, in this framework, a natural explanation. This allows one, among the others, to give an effective description of "virtual" particles (propagating with imaginary "classical" wave vector in the standard spacetime) as objects propagating in the deformed Minkowski space with a "new", but real, wavevector.

The paper is organized as follows.In section 2, we provide the basic elements of DSR, as its axiomatic foundations and the generalization of the Lorentz transformations. The wave propagation in the deformed Minkowski space is discussed in sect. 3. Sect. 4 contains the physical analysis of the results obtained.

2 - Special Relativity in a deformed Minkowski space

Let us briefly review the main aspects of DSR. Its very foundation starts from an axiomatic formulation of the standard special relativity, whose basic postulates can be stated as follows[(5)] :

1 - *Space-time properties*: Space and time are homogeneous and space is isotropic.

2 - *Principle of Relativity*: All physical laws must be covariant when passing from an inertial reference frame K to another frame K', moving with constant velocity relative to K.

Let us notice that in the second postulate it is clearly understood that, for a correct formulation of SR, it is *necessary* to specify the total class, C_T, of the physical phenomena to which the relativity principle applies[(*)].[1] Depending on the explicit choice of C_T, one gets *a priori different* realizations of the theory of relativity (in its abstract sense), each one

[1] The importance of such a specification is easily seen if one thinks that, from an axiomatic viewpoint, the only difference between galileian and einsteinian relativities just consists in the choice of C_T (i.e. the class of mechanical phenomena in the former case, and of mechanical and electromagnetic phenomena in the latter).