DERIVING ELECTROMAGNETISM FROM SPECIAL RELATIVITY: A NOVEL TEACHING-LEARNING MODULE

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INTRODUCTION

In this presentation, a novel teaching-learning module on electromagnetism is proposed, which finds its inspiring source in two sets of unpublished notes by R. P. Feynman (Feynman 1963, 1967-68). It relies on an *ab initio* derivation of Lorentz's force and Maxwell's equations from special relativity (De Luca et al., 2019), which is the opposite of the usual standard historical route. This approach works with the potentials rather than the fields from the very beginning, which implies simpler mathematics. From a methodological point of view, in order to derive electromagnetism from special relativity in a consistent way, one has to develop the latter independently from electromagnetic quantities (e.g., the speed of light), which is indeed possible as shown by some authors (see, for instance, Ugarov 1979). The key observation is that the invariance of the speed of light is not postulated from the beginning, so that the theory builds upon the idea that any interaction should have a limiting speed, which is required to be an invariant according to the principle of relativity. Then, Lorentz transformations can be derived in the usual way and depend on a parameter, the invariant speed, whose value can be fixed by experiments and identified with the speed of light only at the end. These guidelines are the basis for the development of our proposal, which is aimed at introducing electromagnetism at the advanced undergraduate level. Finally, the advantages of this approach with respect to more traditional ones are briefly discussed.

A BRIEF OUTLINE OF THE MODULE

The module is designed for an advanced undergraduate level, so that a basic knowledge of variational principles is required. The starting point is an alternative introduction to special relativity according to the above guidelines. For instance, it is possible to derive Lorentz transformations relying only on the requirements of relativity of inertial reference frames, homogeneity of space and time, isotropy of space and group structure. The next step consists in deriving the form of the Lorentz force from first principles, i.e., building only on the Lorentz invariance of the electric charge and on relativity. That allows one to obtain, as a further bonus, the correct transformation laws for the electric and magnetic fields under Lorentz boosts. A further key point is the introduction of the 4-potential, which allows one to generalize the least action principle of classical mechanics to the relativistic case. Upon varying the action, it is possible to get the homogeneous Maxwell equations. The derivation of non-homogeneous Maxwell equations then follows from the previous results together with one more assumption, i.e., the validity of Coulomb's law. Finally, qualitative properties and shapes of fields in various situations, as well as a bunch of more applicative topics are introduced in the usual way.

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