The non-relativistic limits of the Maxwell and Dirac equations: the role of Galilean and gauge invariance

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Abstract

The aim of this paper is to illustrate four properties of the non-relativistic limits of relativistic theories: (a) that a massless relativistic field may have a meaningful non-relativistic limit, (b) that a relativistic field may have more than one non-relativistic limit, (c) that coupled relativistic systems may be ?more relativistic? than their uncoupled counterparts, and (d) that the properties of the non-relativistic limit of a dynamical equation may differ from those obtained when the limiting equation is based directly on exact Galilean kinematics. These properties are demonstrated through an examination of the non-relativistic limit of the familiar equations of first-quantized QED, i.e., the Dirac and Maxwell equations. The conditions under which each set of equations admit non-relativistic limits are given, particular attention being given to a gauge-invariant formulation of the limiting process especially as it applies to the electromagnetic potentials. The difference between the properties of a limiting theory and an exactly Galilean covariant theory based on the same dynamical equation is demonstrated by examination of the Pauli equation.

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