On the Electromagnetic Origin of Inertia and Inertial Mass

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Abstract We address the problem of inertial property of matter through analysis of the motion of an extended charged particle. Our approach is based on the continuity equation for momentum (Newton’s second law) taking due account of the vector potential and its convective derivative. We obtain a development in terms of retarded potentials allowing an intuitive physical interpretation of its main terms. The inertial property of matter is then discussed in terms of a kind of induction law related to the extended charged particle’s own vector potential. Moreover, it is obtained a force term that represents a drag force acting on the charged particle when in motion relatively to its own vector potential field lines. The time rate of variation of the particle’s vector potential leads to the acceleration inertia reaction force, equivalent to the Schott term responsible for the source of the radiation field. We also show that the velocity dependent term of the particle’s vector potential is connected with the relativistic increase of mass with velocity and generates a longitudinal stress force that is the source of electric field lines deformation. In the framework of classical electrodynamics, we have shown that the electron mass has possibly a complete electromagnetic origin and the obtained covariant equation solves the “4/3 mass paradox” for a spherical charge distribution.

Keywords Classical electromagnetism · Maxwell equations · Classical field theories · Special relativity · General physics · Electromagnetic propulsion

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1 Introduction

Advanced propulsion systems are necessary in order to open up the cosmos to robotic and future human exploration. This quest motivates a renewed interest in studies about the inertial property of matter suggested qualitatively by Galileu in his writings and later quantified by Newton \[1\]. However its conceptualization still remains as an unclear resistance of mass to changes of its state of motion \[2\].

Several approaches were proposed, among them: (i) linking inertia with gravitational interactions with the rest of the universe \[3–5\]; (ii) the evolving notion of a energy replenishing vacuum motivate other line of research sustained in the hypothesis that inertial forces result from an interaction of matter with electromagnetic fluctuations of the zero point field \[6–8\]; (iii) also, other line of thought attribute inertia to the result of the particle interaction with its own field \[9, 10, 14\].

Experimental studies of electrically charged particles animated of high velocities have lead physicists to introduce the notion of electromagnetic inertia besides mechanical inertia. J.J. Thomson (that discovered the electron in studying cathode rays \[15\]) was the first to introduce the idea of a supplementary inertia with constant magnitude for a charge \(q\) with radius \(R\) in a medium of magnetic permeability \(\mu\), to be summed up with the mechanical mass \(m\) such that \(m + 4\mu q/(15R)\) \[16\] (see Ref. \[17\] for a deep historical account). Inspired probably on Stokes \[18\] finding that a body moving in water seems to acquire a supplementary mass, Thomson built a hydrodynamical model with tubes of force displacing the ether.

These studies have not yet achieved a clear and concise explanation of the phenomenon, although different approaches to the classical model of the electron in vacuum may contribute to clarify hidden aspects of the problem \[19\]. Until now there is no experimental support of Mach’s principle as a recent experimental test using nuclear-spin-polarized \(^9\)Be\(^{+}\) ions gives null result on spatial anisotropy and thus supporting Local Lorentz Invariance \[20\]. This supports our viewpoint that inertia is a local phenomena and it is along this epistemological basis that we discuss here the inertia property of matter in terms of an interaction of material particle’s own vector potential with mechanical momentum (in accelerating or decelerating particles). This is substantially the problem of the self-force (or radiation-reaction force), the remarkable phenomena of the interaction of the charged particle on itself. The nonrelativistic form of this force was obtained primarily by Abraham (1903) \[10, 11\] and Lorentz (1904) \[9\], while later Dirac obtained the covariant relativistic expression of the self-force \[21\].

The present paper introduces a new approach to the classical electron problem yielding a pre-relativistic treatment of the motion of an “electron-like” extended charged particle. Previously different types of charged distribution and approaches were considered \[22–24\]. The extended object approach considers an extended charged object of finite size \(\epsilon\) and Ori and Rosenthal \[12, 13\] obtained a universal (i.e., shape-independent), consistent interpretation of the self-force in terms of classical electrodynamics, solving the “4/3 problem” for a spherical charge distribution.

On the basis of the convective derivative terms we attempt to elucidate the physical meaning of the derived terms obtained by using the Lorentz’s procedure at the lowest order. In the framework of our classical electrodynamic approach, the “4/3 problem” can be solved considering the total electromagnetic force acting on an extended-charge particle. This is done by introducing the electromagnetic vector and scalar potentials \((A, \phi)\) and calculating the moving self-field referring to field points that move along with the particle. Using such a procedure the electron mass and inertia can be shown to have a complete electromagnetic