Modified Axion Electrodynamics as Oscillating Polarization and Magnetization of the Vacuum

Michael E. Tobar,[1,*] Ben T. McAllister,[1] and Maxim Goryachev[1]
[1] *ARC Centre of Excellence For Engineered Quantum Systems, Department of Physics, School of Physics and Mathematics, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia.*
(Dated: August 23, 2018)

We present a reformulation of modified axion electrodynamics where the four Maxwell's equations maintain a similar form to the unmodified versions, with all modifications redefined within the constitutive relations between the $\vec{D}$, $\vec{H}$, $\vec{B}$ and $\vec{E}$ fields. In this reformulation the axion induced bound charge density, polarization current density and bound current density are identified along with the associated axion induced vacuum polarization and magnetization, which are shown to satisfy the charge-current continuity equation. This representation is consistent with Wilczek's original calculations from the polarization of vacuum fields. The reformulation is important when considering conversions of axions into photons, relevant in many experimental contexts. For example, when a DC $\vec{B}$-field is applied, oscillating bound vacuum charges and polarization currents are induced at a frequency equivalent to the axion mass. In contrast, when a large DC $\vec{E}$ field is applied, an oscillating bound current or magnetization of the vacuum is induced at a frequency equivalent to the axion mass. Moreover, the integral forms of the equations can be used to clearly define the boundary conditions between distinct media either with or without axion induced vacuum polarization or magnetization. This provides clarity when considering experiments sensitive to axion induced electric and/or magnetic effects inside or outside the high DC field region. For example, a capacitor in a high DC magnetic field can act as a detector for low-mass axions without suppression of of the signal due to electromagnetic shielding. Also, we calculate the voltages and currents induced by axions in an inductive sensor under a DC electric field, which is the dual experiment to a capcitive sensor under a DC magnetic field.