Inertial effects in systems with magnetic charge

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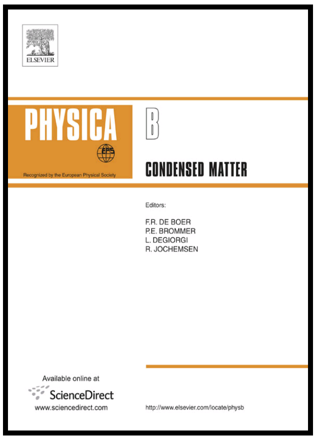

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Inertial effects in systems with magnetic charge

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Abstract

This short article sets out some of the basic considerations that go into detecting the mass of quasiparticles with effective magnetic charge in solids. Effective magnetic charges may be appear as defects in particular magnetic textures. A magnetic monopole is a defect in this texture and as such these are not monopoles in the actual magnetic field **B**, but instead in the auxiliary field **H**. They may have particular properties expected for such quasiparticles such as magnetic charge and mass. This effective mass may – in principle – be detected in the same fashion that the mass is detected of other particles classically e.g. through their inertial response to time-dependent electromagnetic fields. I discuss this physics in the context of the "simple" case of the quantum spin ices, but aspects are broadly applicable. Based on extensions to Ryzkhin's model for classical spin ice, a hydrodynamic formulation can be given that takes into account inertial and entropic forces. Ultimately, a form for the susceptibility is obtained that is equivalent to the Rocard equation, which is a classic form used to account for inertial effects in the context of Debye-like relaxation.

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1. Introduction

The subject of isolated magnetic charges (e.g. monopoles) is a perennial one in modern physics. Dirac argued that the existence of single magnetic monopole anywhere in the universe would account for the quantization of the electric charge [1, 2]. And in grand unification theories magnetically charged particles appear naturally [3]. However, as is learned by all beginning physics students, no definitive signatures of fundamental magnetic charges have been found[1] and one can safely write the magnetic Gauss's Law as $\nabla \cdot \mathbf{B} = 0$. However there are material systems where effective magnetic charge exists. Generally speaking these magnetic charges can be stabilized because of some particular magnetic texture enforced in the low energy states. The monopole is a defect in this texture and therefore these are not monopoles in the actual magnetic field **B**, but instead in the auxiliary field **H**. Nevertheless, in many circumstances they possess properties that one would expect for fundamental monopoles. They have magnetic charge and may be manipulated in a fashion consistent with their particle nature. And in many situations they can exhibit effects consistent with inertia and mass.

One of the simplest cases where such monopoles may arise is as domain walls in quasi-1D ferromagnetic nanowires made of classical soft ferromagnets. The domain wall carries magnetic charge and can be manipulated by external fields. In classical magnets as such, the magnetic texture encompasses many spins that give effective internal degrees of freedom that can store energy when they are in motion, which can give inertia and an effective mass e.g. effective hard modes of the system can impart inertia to soft modes when the hard modes are integrated out [5]. Döring was the first to show that inertia can arise in this fashion for Bloch domain walls [6]. Domain walls can be moved by a z-axis applied homogeneous magnetic field. The applied field exerts a torque on precessing spins in the domain wall, which pulls the spins out of the plane perpendicular to the direction of motion of the wall. An internal field perpendicular to the wall is created

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[1] On Valentine's day in 1982 an almost perfect signal of one Dirac unit of magnetic charge passed through a superconducting loop detector [4]. Although not for lack of trying, the results of this Valentine's Day monopole "massacre" were never reproduced.