06/1301 The Gravitomagnetic London Moment

Type of activity: Medium Study (4 months, 25 KEUR)

Background and Motivation

Superconductors have two well-known effects: the Meissner-Ochsenfeld effect (a magnetic field cannot penetrate a superconductor) and the London moment (a rotating superconductor generates a magnetic field). Both effects can be understood as a consequence of the photon acquiring a mass inside the superconductor due to symmetry breaking (BCS theory). This mass is actually quite big, about one thousandth of the electron mass.

Completely independent of this, one can describe general relativity in a region with weak gravitational fields by a vector field similar to the photon (weak-field approximation). It is then seen that the gravitational correction to the London moment (the gravitomagnetic London moment) is described by the gravitomagnetic field and enters the formulae in a very similar way to the normal magnetic field (this was found in [1,2] already). A straightforward calculation shows that this effect should be far too small to be detectable.

However, there is an on-going debate in theoretical and experimental physics about anomalous effects in the gravitational coupling to coherent matter, in particular to superconductors. One might wonder what happens if the gravitational symmetries were broken in a superconductor as well and if as a consequence the graviton became massive. A simple calculation shows that an ad-hoc ansatz of Proca-type instead of Maxwell-type equations for the gravitomagnetic and/or the gravitoelectric fields can yield a significant enhancement of gravitational effects in superconductors, in particular of the gravitomagnetic London moment.

Research and Study Objectives

The objectives of the study are the systematic investigation of Proca-type equations and its consequences for the gravitomagnetic and gravitoelectric fields as well as the derivation thereof from a complete theory of gravitation (general relativity). The questions in particular include:

1) Are enhanced gravitational effects a general result from Proca-type equations? If not, what are the additional assumptions needed to come to this conclusion?

2) Within the massive graviton model:

   a) How can a massive gravitomagnetic/gravitoelectric field emerge from general relativity?

      i) It is known that the standard Higgs mechanism does not work for the graviton quite generally. However there exists an interesting proposal by Nima Arkani-Hamed et al. ([3,4] and references therein) how to achieve a Higgs phase of gravity. In that scenario a field with a shift symmetry is needed, which acquires in its ground-state a linearly space-time dependent vacuum expectation value breaking local Lorentz and diffeomorphism invariance. Arkani-Hamed et al. choose a scalar field with $<\phi> = ct$ and study cosmological consequences. For the problem discussed here this ansatz most probably is insufficient: A scalar field can give a mass to one component of the graviton only (which is intuitively clear as it just adds one degree of freedom.) Besides different vacuum structures of the scalar fields a more general approach of the field content could be investigated. Preliminary calculations showed that a free $U(1)$ gauge field could yield interesting solutions with a similar behavior as the proposal of Arkani-Hamed et al.

ii) Still, it appears to be difficult to reproduce the Proca equations for linearized gravity exactly: Any vacuum contribution of the form $m^2 h_{\mu\nu}$ by covariance in the full theory should be part of a cosmological constant and thus deforms the vacuum structure instead of providing a mass for the gravitomagnetic field. Possible ways out include more complicated theories of gravitation (instead of general relativity) or more complicated mass terms that have a similar effect onto the equations of motion of the gravitomagnetic field.

b) Why should the superconductor produce one of the effects that that should be found from the previous point? Do there exist candidates for symmetry breaking fields?

3) Do there exist different models with similar phenomenological effects?

Quite generally we are interested in results that are based upon (theoretically as well as experimantally) well-established theories, eventually enlarged by some ad-hoc models, and that do not rely too much on technical details of purely theoretical extensions thereof (such as string theory, loop quantum gravity, brane-world scenarios etc.)

Literature

[1] B.S. DeWit, "Superconductors and gravitational drag," Phys.Rev.Lett. **24** (1966) 1092.

[2] D.K. Ross, "The London equations for superconductors in a gravitational field," J.Phys.A: Math Gen **16** (1983) 1331.

[3] N. Arkani-Hamed, H.C. Cheng, M.A. Luty and S. Mukohyama, "Ghost condensation and a consistent infrared modification of gravity," JHEP **0405** (2004) 074 [arXiv:hep-th/0312099].

[4] N. Arkani-Hamed, H.C. Cheng, M.A. Luty, S. Mukohyama and T. Wiseman, "Dynamics of gravity in a Higgs phase," arXiv:hep-ph/0507120.