Pion Condensates in an External Magnetic Field

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Quantum Chromodynamics (QCD) is the theory of strong interactions that explains how hadrons such as protons, neutrons, and pions form stable bound states. It is impossible to study a system of baryons directly using QCD because the traditional analytical and computational methods, consisting of perturbation theory and Lattice QCD respectively, break down due to the fermion sign problem. However, a regime of finite isospin QCD, whose ground state is a system of pions, avoids the fermion sign problem and thus can be studied numerically. Previous studies have found that at low isospin density, the ground state of the finite isospin system is a superfluid condensate, a unique form of matter in which all particles assume the same lowest-energy quantum state. This work examines finite isospin QCD, in which pions are coupled to photons, in the presence of an external magnetic field. It is found that this system has at least three phases: a spatially homogenous superconducting state under low external magnetic fields, a spatially inhomogenous vortex- containing state under moderate fields, and a normal state with uncondensed pions for large fields. The Hamiltonian for the system was numerically minimized to find the ground state characteristics for a single vortex in the vortex-containing phase. The magnetic field at which the system transitions from the homogenous superconductor state to the inhomogenous vortex state was also numerically calculated. This study extends knowledge of finite density strongly interacting systems, enabling a better understanding of neutron stars, which are thought to contain pion condensates in their highly dense cores.

Awards Won:

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