Axions in Chiral Perubation Theory

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Abstract

About 25 % of the universe's energy density is dark matter (DM). Even though there is clear observational evidence for DM throughout different length scales, ranging from galaxy rotational curves to anisotropies in the cosmic microwave background, the nature of DM is still unknown. In this study we investigate axion-like particles (ALPs), a class of candidates for ultralight DM in the mass range 10^{-20}eV to 10^{-6}eV. We derive the effective quadratic ALP-photon coupling at one-loop order using the framework of chiral perturbation theory (ChPT).

The axion was originally introduced to solve the strong charge-parity (CP) problem of quantum chromodynamics (QCD). In the QCD Lagrangian, the CP-violating term which is allowed by SU(3) gauge symmetry appears with a coupling parameter θ. For generic values of θ one expects a sizeable and measurable neutron electric dipole moment (eDM). However, experimental data suggests that the neutron's eDM is consistent with zero. This leads to a fine-tuning of θ in the QCD Lagrangian. The QCD axion resolves this fine-tuning problem by dynamically relaxing the neutron eDM to zero. While the QCD axion is a light pseudoscalar whose mass is generated non-perturbatively by QCD, axion-like particles (ALPs) constitute a broader class of pseudoscalars that allow for a non-zero bare mass and more general couplings.

In this work, we consider QCD in the two-flavour chiral limit and couple the ALP to the CP-violating operator and to quarks via a chiral, derivative interaction. Using ChPT we construct the low-energy effective Lagrangian and express the degrees of freedom in terms of pions, the pseudo-Goldstone bosons of the spontaneously broken chiral symmetry. From this effective Lagrangian we derive both mass and kinetic mixing between the ALP and the neutral pion, as well as the Feynman rules . We use these results to compute the effective quadratic ALP-photon coupling at one-loop order. Finally, we discuss general phenomenological implications of the effective ALP-photon vertex for low-energy experiments and DM searches.