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Probing Axion-like Particles: Novel Detection Channels and Expanding Experimental Sensitivity for Dark Matter and Solar ALPs

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Probing Axion-like Particles: Novel Detection Channels and Expanding Experimental Sensitivity for Dark Matter and Solar ALPs

Axions and axionlike particles (ALPs) represent a promising avenue in the quest for new physics, potentially shedding light on the profound mysteries enveloping our Universe, including the nature of dark matter and dark energy. ALPs are well-motivated dark matter (DM) candidates and can be produced in astrophysical environments and terrestrial laboratories. In recent years there has been remarkable progress in the physics of axions and ALPs in several directions. The primary contribution of this study is two-fold: firstly, it involves the identification of novel detection channels aimed at probing $g_{a\gamma\gamma}$ through terrestrial experiments. This new inelastic inverse Primakoff scatterings (inverse Primakoff Ionisation - IP_{ion}) between ALPs and matter as promising avenues, offering a method to investigate relic ALPs. The differential cross-section of this new channel is computed using sophisticated *ab – initio* atomic many-body theory. Secondly, expanding the parameter space in (m_a , $g_{a\gamma\gamma}$) for laboratory-based investigations for solar-ALPs and DM-ALPs. This was achieved by using TEXONO data taken with a point-contact germanium detector and high-purity germanium detector at the Kuo-Sheng Reactor Neutrino Laboratory by the TEXONO Collaboration. These detectors were specifically chosen for their dual attributes of low threshold and high energy reach, coupled with outstanding energy resolution for precise spectral peak detection [1], [2]. Furthermore, XENONnT data obtained from liquid xenon in the $1{-}140$ keV_{ee} [3] range was also utilized due to its extensive exposure and advantageous characteristics of low threshold and background. For solar ALPs which are relativistic, inverse Primakoff elastic scattering (IP_{el}) with a one-photon final state is the dominant channel. The DM-ALPs are non-relativistic and interact predominantly via the two photon decay (TPD) and IP_{ion} channels. The exclusion regions at 90% CL from the TEXONO and XENONnT data for $g_{a\gamma\gamma}$ on solar-ALPs are derived. With the detection efficiencies taken into account, the standalone sensitivity regions for DM-ALPs analysis independent of other processes are derived. The upper reaches of the sensitivity regions are bounded by terrestrial attenuation by the Earth and its atmosphere before the DM-ALPs can reach the detectors. The TPD lifetime of ALPs has to be longer than the age of the Universe in order for the DM-ALP to reach and be observable in terrestrial experiments. This implies part of the (m_a, $g_{a\gamma\gamma}$) parameter space is not accessible by the direct experimental searches of DM-ALPs while future projects would be able to evade the stability bound and open new observable windows for DM-ALPs. As an extension of this work, presently we are working on establishing a robust axio-electric differential cross-section for ALPs utilizing advanced many-body techniques through a global approach considering the coupling between axions and photons, as well as axions and electrons.

References

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