Exercises on Axions

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Exercise 1. Let us suppose that the Dark Matter's main component is an ultralight boson with mass $m_b c^2 = 1 \mu eV$.

(a) What is the de Broglie wavelength λ_{dB} of such a boson?

(b) Estimate how many bosons one would find in a volume of ${\lambda_{dB}}^3$.

Consider that the virialised velocity of Dark Matter in the Milky Way is of the order $10^{-3}c$, and the local Dark Matter density ρ_{dm} is $0.45\, GeV/cm^3$.

Exercise 2. The term in the Lagrangian describing the axion-photon interaction is

$$\mathcal{L}_{A\gamma} = \frac{g_{A\gamma}}{4} A\, F^{\mu\nu} \widetilde{F}_{\mu\nu} \tag{1}$$

(a) Derive the form of 2, as a function of $\boldsymbol{E}$ and $\boldsymbol{B}$

$$\mathcal{L}_{A\gamma} = g_{A\gamma}\, A\, \boldsymbol{E} \cdot \boldsymbol{B} \tag{2}$$

(b) Does this term violate CP-symmetry? Explain.

Exercise 3. We are thinking of conducting a simple LSW experiment, using two magnets each of length L and strength B. The laser we plan to use will have an angular frequency of ω. Up to what ALP mass do we maintain maximum sensitivity?

Exercise 4. The signal power P_{sig} of microwave cavity experiments looking for relic axions is determined by a combination of theoretical parameters of the axion physics (among which the axion mass m_a, the coupling constant $g_{a\gamma\gamma}$, the local Dark Matter density ρ_{DM}) and experimental parameters of each experiment (cavity resonance frequency ω_c, cavity volume V and mode C_{mnl}, external magnetic field strength B, quality factor Q...).

The ADMX experiment, sensitive to DFSZ axions, presents a power of the order of $P_{sig} \sim 10^{-23} W$. If a Dark Matter axion with $m_a = 3.3 \mu eV$ with a DFSZ coupling exists, what is the average number of photons emitted from the cavity every second? Assume that if the cavity is tuned to the correct frequency.

Exercise 5. An axion helioscope uses a uniform magnetic field with a strength of $B = 9\, T$ along a length $L = 10\, m$.

(a) What axion masses is the helioscope sensitive to when the magnet bores are kept in vacuum?

(b) In a second phase of the experiment, the vacuum is filled with gas at a very low pressure. What range of masses is the experiment sensitive to?

(c) What ar the values if the magnet is filled with He at a pressure of $p = 5.49\, mbar$?

Bibliography

1. The Search for Ultralight Bosonic Dark Matter, Sprinder, Ed. D. F. Jackson Kimball and K. van Bibber, 2023. (Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/))

2. J. K. Vogel, CAPA/UNiveristy of Zaragoza, notes on lectures on Astroparticle physics.