
Dark Matter (WS 2018/19) - Problem sheet 10

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Axions

Originally proposed to solve the so-called strong CP problem, axions also have become an interesting candidate to make up the dark matter in the universe. On this exercise sheet, we will estimate an upper bound on the mass of such particles and have a look at experimental approaches trying to probe their existence.

10.1 Decay of Axions 5 Points

First, we try to calculate a limit on the axion mass and coupling strength, given that axions should be stable with respect to the age of the universe (13.8×10^9 years). As it was stated in the lecture, the axion mass m_a and coupling constant closely depend on each other by the following relation.

$$m_a = 57 \cdot \left(\frac{10^{11} \text{ GeV}}{f_a} \right) \mu\text{eV} \quad (1)$$

Now we want to consider the decay of an axion into a pair of photons. The width of the decay line $\Gamma_{a \rightarrow \gamma\gamma}$ for this process can be computed and is given below.

$$\Gamma_{a \rightarrow \gamma\gamma} = \frac{G_{a\gamma\gamma}^2 m_a^3}{64\pi} \quad (2)$$

Where $G_{a\gamma\gamma}$ is describing the coupling strength. In a simplified KSVZ model it can be calculated in the following way.

$$G_{a\gamma\gamma} = -\frac{\alpha}{2\pi f_a} \left(\frac{2(4+z)}{3(1+z)} \right) \quad (3)$$

Here $z = m_u/m_d$, describes the mass ratio between up and down quark and $\alpha = 1/137$ being the electromagnetic coupling constant.

Assuming that $z = 0.56$, please compute an upper limit on m_a . (*Hint: The width of a decay line is directly related to the lifetime of a particle.*)

10.2 Searches for Axions 5 Points

Have a look at this paper <https://arxiv.org/pdf/1705.02290.pdf> by the CAST collaboration and answer the following questions.

a) Briefly describe the setup that is used for the CAST experiment.

- b) By which process can axions be detected with this instrument? What kind of background processes can disturb the measurement and how are they suppressed?
- c) During parts of the day, the helioscope is used to track the sun, while recording data. What kind of measurements are done, while the sun is not tracked? Why is this data important?
- d) In the paper it is described that during some periods, the conversion pipes were filled with helium. Explain why this was done.
- e) Look up and describe, how an x-ray telescope (XRT) like the one used by the CAST experiment works.

10.3 How can light shine through a wall? 2 Bonus Points

Describe how a "light-shining-through-walls" setup works. How can this help to experimentally constrain the mass and coupling of axion-like particles?

(You can have a look at the following paper <https://arxiv.org/pdf/1410.1633.pdf>).