Measurement of the Neutron Lifetime in the "Accordion-like" Storage Trap

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Introduction

Precise measurement of the neutron lifetime is important in particle physics and cosmology. Along with the Asymmetry parameter, A, the value of the neutron lifetime is important to test the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. The neutron lifetime also affects the primordial helium abundance and the calculation of the helium abundance can be used to test cosmological models, like the Big Bang theory [2]. Also, the discrepancy between the most precise value of the neutron lifetime measured using the beam experiment [3] and the bottle experiment [2] has increased from 2.9 σ (in 2005) to 3.8 σ [3] (in 2013). This discrepancy could be resolved by conducting new and improved measurements.

Accordion concept and principle of the experiment

Ultracold neutrons (UCN) have kinetic energies of the order of 100 neV. Due to low energies, UCN can reflect elastically from the walls of container, made of certain materials, at all angles of incidence. Hence, they can be stored inside a closed container for several hundred seconds.

An accordion [4], shown in Fig. 1, is a horizontal cylindrical trap which is placed in a vacuum chamber. An important feature of the device is that the surface area remains constant even if the volume of the UCN trap is changed in a wide range. Bellows system is made of stainless steel and the system allows gap-free volume changes with precision 0.1 mm. The walls of the storage volume were covered with Low Temperature Fomblin (LTF) which has a loss coefficient, $\eta = 5 \times 10^{-6}$ in the temperature range from 105 K to 150 K [4].

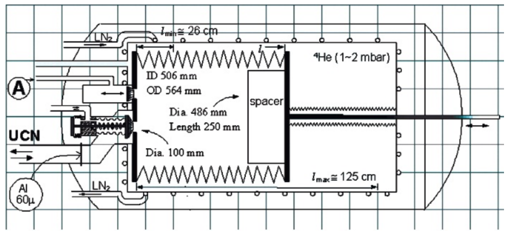

FIG. 1: Schematic view of the "accordion system"[4].

The ultracold neutrons are filled in to the accordion for time t_1 (t_2) and the remaining number of neutrons N_1 (N_2) are counted. This gives the lifetime of the neutron in the bottle (i.e. the storage lifetime), which is given by [4]

$$\tau_{st} = \frac{t_2 - t_1}{\ln(N_2 - N_1)} \quad (1)$$

with

$$\tau_{st}^{-1} = \tau_n^{-1} + \tau_w^{-1} \quad (2)$$

where, τ_n is the neutron lifetime and τ_w^{-1} is the wall loss probability per second and is given by,

$$\tau_w^{-1} = \frac{\nu\mu(v)}{\lambda} \quad (3)$$

where, ν is the wall collision rate, $\lambda = 4V/S$ is the mean free path between the two wall

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collisions, V is the volume of the trap, S is the surface area of the trap and $\mu(v)$ is the mean velocity dependent loss rate per bounce [4].

To measure the free neutron lifetime (τ_n), inverse storage lifetime is plotted against inverse mean free path. This plot will be linear and we extract the wall loss by extrapolating to the point where there is no collision, i.e. for $\lambda = \infty$. The y-intercept point of this linear fit gives the inverse of the neutron lifetime.

Measurements and Results

This section presents the experimental results of the neutron lifetime experiment conducted at the Institut Laue Langevin, Grenoble.

Storage Lifetime

The measured value of the storage lifetime, $\tau_{st} = 220.9$ s, was not as high as expected. In order to increase the probability for the oil to cover the entire surface of the trap, we evaporated the oil at different temperatures. We also added different amounts of helium and oil to the trap, but no significant increase in the storage trap was measured. There could have been some losses due to the presence of Fe_2O_3 particles at the welds of the bellows system but it was not possible to check for the magnetic particles and the impact they could have on the storage lifetime.

Value of the Neutron Lifetime

As shown in the Fig. 2, inverse storage lifetime measured for each volume is plotted against the inverse mean free path. The y-intercept gives the value of inverse neutron lifetime. Therefore, the measured value of the neutron lifetime obtained is $\tau_n = 860 \pm 48$ s

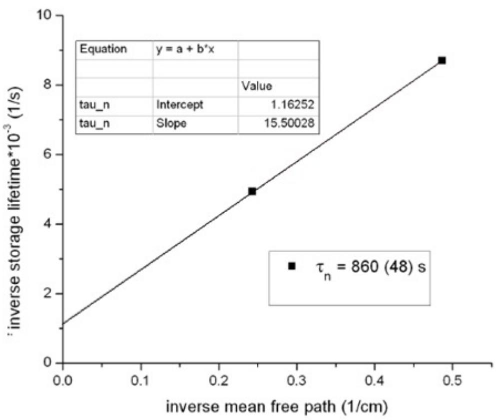

FIG. 2: Plot of inverse storage lifetimes as a function of the inverse mean free path of the trap. Error bars are smaller than the data points.

Conclusion

We report the progress towards a measurement of the neutron lifetime using an accordion-like storage trap. Although in principle using the accordion to measure the neutron lifetime has some advantages, we encountered difficulties in obtaining a high storage lifetime. As it was not possible to check for the magnetic particles and the effect they can have on the storage lifetime, the loss due to magnetic particles near welds is the most likely possibility for the low storage lifetime. Even though the storage lifetime was not high enough, the value of the neutron lifetime measured at low temperatures, $\tau_n = 860 \pm 48$ s is consistent with the current world average value of the neutron lifetime, $\tau_n = 880.3 \pm 1.1$ s [5].

Acknowledgments

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