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Measurement of the neutron lifetime using a gravitational trap and a low-temperature Fomblin coating

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Abstract

We present a new value for the neutron lifetime of $878.5 \pm 0.7_{\text{stat}} \pm 0.3_{\text{syst}}$. This result differs from the world average value (885.7 ± 0.8 s) by 6.5 standard deviations and by 5.6 standard deviations from the previous most precise result [Phys. Lett. B 483 (2000) 15]. However, this new value for the neutron lifetime together with a β-asymmetry in neutron decay, A_0, of $-0.1189(7)$ [Phys. Rev. Lett. 88 (2002) 211801] is in a good agreement with the Standard Model.

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Keywords: Ultracold neutrons; Neutron lifetime

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1. Introduction

The decay of the free neutron into a proton, an electron and an antineutrino is related to the weak interaction process. In the Standard Model the probability of this process or the lifetime of the free neutron is related to the vector G_V and axial G_A weak interaction coupling constants. The neutron lifetime has important implications in particle physics, in neutrino-induced reactions and in cosmology. The neutron lifetime together with angular correlation coefficients of the decay of a polarised neutron allows deduction of the axial and vector coupling constants only from neutron decay data. The main element of the Kobayashi–Maskawa matrix, V_{ud}, has to be determined with the

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highest accuracy to check for eventual deviations from the Standard Model which are currently under discussion [3].

The observed deviation from the unitarity condition for the Cabibbo–Kobayashi–Maskawa matrix using present data is about 2.7 standard deviations. The origin of this deviation is unclear. This situation requires more precise measurements of β-asymmetry—A_0 and new measurements of the neutron lifetime.

Today, the weighed mean value of the neutron lifetime is 885.7(8) s. The accuracy of this world average was improved by the lifetime experiment of a group from KIAE, Russia [1]. Their result ($885.4 \pm 0.9_{\text{stat}} \pm 0.4_{\text{syst}}$) has an accuracy that is at least 3 times better than that of the other contributing experiments. So the present world mean value of the neutron lifetime is mainly determined by the result of only one experiment, therefore the new experimental measurements are important.

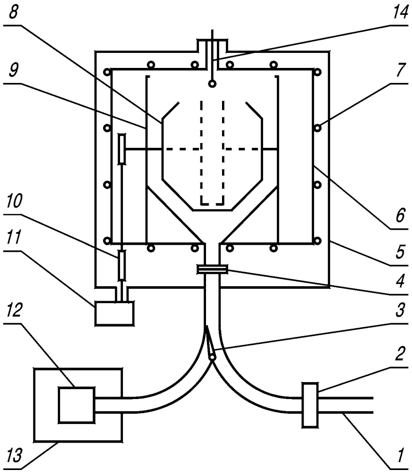

Fig. 1. The scheme of "Gravitrap", the gravitational UCN storage system. 1: neutron guide from UCN Turbine; 2: UCN inlet valve; 3: beam distribution flap valve (shown in the filling position); 4: connection unit; 5: "high" vacuum volume; 6: "rough" vacuum volume; 7: cooling coils; 8: UCN storage trap (the narrow cylindrical trap is shown by a dashed line); 9: cryostat; 10: mechanics for trap rotation; 11: stepping motor; 12: UCN detector; 13: detector shielding; 14: evaporator.

2. Experimental set-up and method of measurement

The present measurements were carried out at the high flux reactor at ILL in Grenoble, France using the PF2/MAM instrument; the experimental set-up is sketched in Fig. 1. It is a gravitational trap for ultra cold neutrons (UCN) and at the same time it can be used as a differential gravitational spectrometer. Therefore the distinguishing feature of this experiment is the ability to measure the UCN energy spectrum after its storage in the trap.

The UCN storage trap 8 is mounted inside a cryostat vacuum vessel 9. The trap 8 has a window that can be rotated about a horizontal axis so that UCN are held in the trap by gravity when the trap window is in its upper position.

UCNs enter the trap via the neutron guide 1, the opened UCN inlet valve 2 and the distribution flap valve 3. Filling takes place when the trap window is in the down position. After the trap is filled it is rotated into the up position.

A double walled vacuum system was used with separate "high" 6 and "rough" 5 vacuum vessels. The pressure in the cryostat vacuum vessel was 5×10^{-6} mbar; at this pressure, the residual gas has a small effect (0.4 s, see below) on storage time for the UCN in the trap. To cool the trap we used heat exchange between the trap and the cryostat tank; to do this helium gas was flowed through the cryostat vacuum vessel and removed before carrying out the neutron lifetime measurements.

The height of the trap window relative to the trap bottom defines the maximum energy of UCN that can be held in the trap. Different window heights correspond to different cut-off energies for the UCN spectrum. Such a rotatable trap is a gravitational spectrometer. The spectral dependence of the storage time can be measured by turning the trap window downward in steps. The trap was kept in each intermediate position during 100–150 s to detect UCN in the corresponding energy range. The same procedure also measures the spectrum of the trapped UCN.

The neutron lifetime is measured with the size extrapolation method using two sizes of UCN trap. The first is a quasi-spherical trap consisting of a cylinder about 84 cm in diameter and 26 cm wide, capped by two truncated cones each 22 cm high, with small diameters of 42 cm and the second a 76 cm diameter cylindrical trap that was 14 cm long between its end faces. The second trap increases the neutron collision rate with the walls of the trap by a factor of about 2.5.