Long-term storage of neutrons in a nonuniform magnetic field

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Experiments have shown for the first time that neutrons can be confined for a time greater than 700 s in a simply connected region formed by combining a nonuniform magnetic field and a gravitational potential.

1. Introduction

In the present study we consider the possibility of storing neutrons in a magnetic confinement system with a simply connected confinement region over a time approximately equal to the lifetime of a free neutron. Vladimirskiĭ,[1] who was the first one to raise this problem, considered the presence in such a confinement system of branch lines and points at which the magnetic field vanishes to be the sole and completely surmountable obstacle. Experiments on the storage of neutrons in confinement systems with such confinement regions[2,3] have yielded storage times of 34 ± 7 s (Ref. 2) and 303 ± 37 s (Ref. 3). Kosvintsev[2] attempted to explain the result solely in terms of the neutron depolarization at the field nodes, and the storage time obtained by Abov *et al.*[3] is inconsistent with the depolarization estimates. Another pathway for the removal of neutrons was therefore assumed to be present.[4] We report here the results of an experiment on neutron confinement in a confinement system.

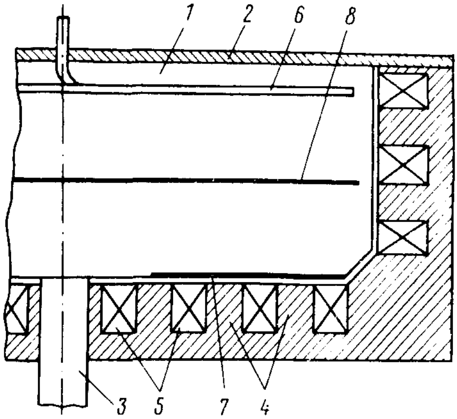

FIG. 1. Magnetic confinement system for ultracold neutrons. 1—Vacuum chamber; 2—vacuum-chamber lid; 3—pipe for injection and removal of neutrons; 4—electromagnet poles; 5—electromagnet windings; 6—correcting winding; 7—polyethylene absorber; 8—auxillary absorber.

2. Experiment

Since detailed data on the neutron storage system were reported in Refs. 3 and 5, we present here only a schematic drawing of the magnetic confinement system (Fig. 1). On the basis of the results of the preceding experiment we can assume that the time $\tau = 303 \pm 37$ s that was reached previously is determined primarily by neutrons whose energy range exceeds the magnetic storage energy limit. It was shown in Ref. 5 that the confinement system holds neutrons for a time typically in excess of 500 s, but the number of these neutrons is no greater than 0.2 neutron/cycle.

To verify these estimates and assumptions, we placed an ultracold neutron absorber at the level of the upper boundary of the confinement region (150 mm from the chamber bottom). As an absorber we used diffusion oil deposited on a round aluminum substrate which was suspended horizontally. We used an additional absorber, because the polyethylene disk at the bottom of the vacuum chamber could not adequately absorb the high-energy neutrons. A significant contribution may come from neutrons with an energy greater than the energy limit of the magnetic confinement (which is determined by the weakest field near the injection branch pipe) but less than the magnetic potential at the bottom of the chamber near the polyethylene disk.

We have carried out series of measurements with the confinement times 20, 80, 160, 280, 400, 600, and 880 s. At the end of the confinement interval, the magnetic shutter was opened and the detector, whose counting up to this point was essentially the same as that of the background, detected the neutrons escaping from the confinement system. The results of the experiment are shown in Fig. 2, in which the number of neutrons passing through the detector after being released is plotted as a function of the confinement time. The count is given after subtracting the background. The count did not exceed 0.009 pulse/s at any point during the experiment. We can see from the plot and from the given estimates that the storage curve is described by the sum of the two exponential functions. The "short" one has a decay time of 210 ± 60 s and the "long" one has a decay time of no less than 700 s at the 68% significance level. Consequently, the neutrons in the storage volume can be divided into a "short" com-

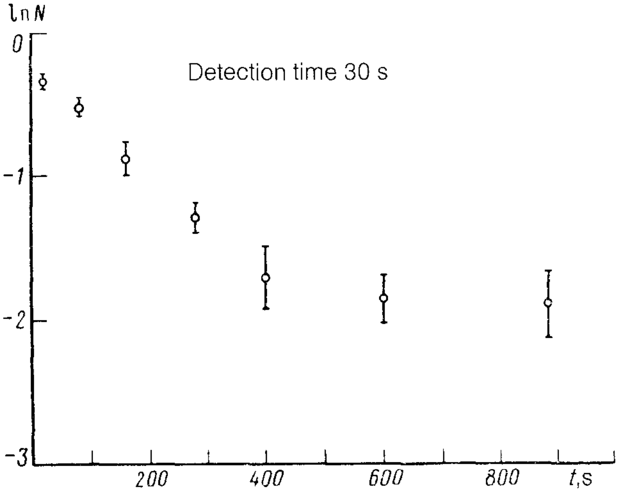

FIG. 2. The number of neutrons remaining in the confinement system after a storage time t and the number of neutrons detected by the detector during a 30-second detection versus the storage time.

ponent and a "long" component, depending on whether they interact with the magnetic field, the chamber walls, or the ultracold neutron absorber.

It can be seen from a comparison of the results of the experimental studies of Refs. 3 and 5 that the placement of the ultracold neutron absorber at the upper boundary of the storage region reduced significantly the number of neutrons in the storage device (down to 0.8 neutron/cycle). The short component, nevertheless, remained intact and its storage time was $\tau \simeq 200$ s, i.e., it changed in comparison with the results of Ref. 3, where it was found to be $\tau \simeq 300$ s.

We recall that the lateral surface of the vacuum chamber and the larger part of the bottom are actually not part of the effective ultracold neutron absorber and can reflect neutrons. The upper absorbing screen is placed in such a way that it can absorb neutrons with vertical component of the velocity greater than the cutoff velocity of the magnetic storage. There is also a fraction of neutrons with a vertical velocity component that does not exceed the cutoff velocity and with an appreciable horizontal velocity component that accounts for the fact that the total kinetic energy exceeds the confinement energy limit. The escape time of such neutrons is determined by the mixing velocity of the horizontal and vertical components, which may account for the storage time $\tau \simeq 200$ s.

3. Conclusions

We conclude from our results that the number of neutrons stored by the long-lived component is approximately equal to the previous estimates[5] which were based on the ultracold neutron flux at the entrance to the confinement system. It is also clear that a long-term storage of neutrons over a time comparable to the lifetime of a free neutron is entirely possible in confinement systems with a nonuniform magnetic field and with a simply connected storage region. Only the phase volume of the confinement system and the initial ultracold neutron flux must be increased in order to obtain a sufficiently large statistical base.

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