Storage of ultracold low-energy neutrons in vessels with condensed metallic walls

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Results are presented of measurements of the storage time of UCN with energy ~20 neV in vessels with condensed metallic walls. The ~650 sec storage time obtained for Be is the maximum attainable at present. The phenomenology of anomalous leakage of UCN is considered.

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It has by now been established[6] that anomalous losses of UCN in the walls of the containing vessels[1-5] are due to immediate heating of the UCN to an energy close to thermal. This heating is possibly due to the presence of the hydrogen atoms on the wall surface.[7-11]

1. In the present study we have used as the walls of the vessel in which to confine the UCN a freshly prepared layer of metal, sputtered either immediately prior or during the time of storage of the UCN in the vessel. The use of a low-energy UCN

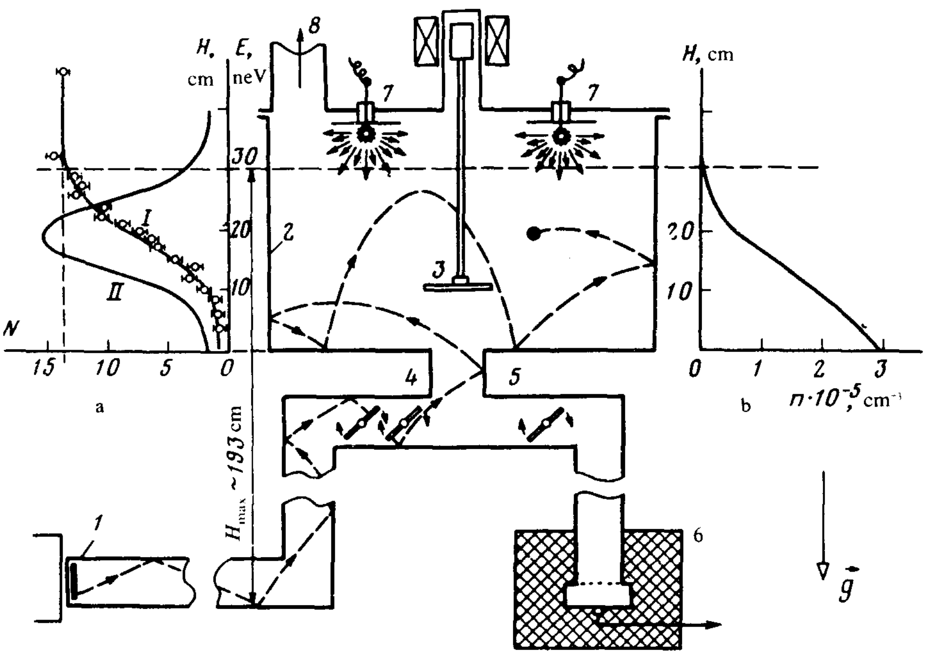

FIG. 1.

spectrum ($\sim$20 neV) has made it possible to increase the choice of material having a relatively low limiting velocity ($v_{\rm lim}$) and made it possible to reduce the frequency (ν) of collision of the UCN with the walls to the minimum possible under conditions of the earth's gravity at the given vessel dimensions.

2. The UCN of energy 50–190 neV produced in the converter (1) (Fig. 1) were lifted in the gravity field along the vertical section of the neutron guide, losing thereby part of their kinetic energy and filling a cylindrical vessel (2) of 57 cm diameter and 32 cm high, located at a height 164 cm. The spectrum of the stored neutrons was determined by measuring the dependence of the number N of the UCN that remained in the vessel (50 sec after the filling) on the height of the polyethylene cover (the effective absorber of the UCN) above the bottom of the vessel (Fig. 1a, curve 1). It turned out that the spectrum is well described by a Gaussian distribution with average energy 19 neV and variance 6 neV (curve II). The filling of the vessel, the confinement, and the outflow ($\sim$10 sec) of the UCN to the detector (6) were effected with baffles (3,4,5). The dependence of the number of remaining UCN in the vessel on the confinement time t is well described by the relation $N=n_0\exp(-t\tau_{ex}^{-1})$, where τ_{ex} is the experimentally observed storage time. The metal evaporators (7) and the port (8) to the diffusion pump were located above the maximum height to which the UCN corresponding to the upper energy limit of the spectrum could rise.

3. For an aluminum vessel etched in an NaOH solution and washed with distilled water we had $\tau_{ex}=170\pm15$ sec, and after sputtering on it $\sim$0.5 μm aluminum, $\tau_{ex}=230\pm14$ sec. Measurements with sputtered layers $\sim$0.5 μm thick have yielded well-reproducible values of τ_{ex}(sec), namely 298 ± 17, 338 ± 9, 435 ± 23, 439 ± 17, and 645 ± 25 for Zn, Cu, Pb, Bi, and Be, respectively. After two days in vacuum (10^{-5} Torr) the vessels revealed no noticeable decrease of τ_{ex}. After contact of the aluminum with the atmosphere for two weeks, τ_{ex} decreased to 170 ± 20 sec, in the case of Bi a certain decrease of τ_{ex} was observed even after one day, while for Cu no change of τ_{ex} was observed after one week. In some experiments the UCN were stored in a vessel on the walls of which Al was deposited simultaneously by evaporation. The sputtered flux of Al atoms "screens" constantly the condensed impurities from the residual vacuum, and thus the UCN should be reflected from the freshly prepared Al layer. At a vacuum $\sim10^{-6}$ Torr and at condensation rates 3×10^{-8} g cm^{-2} sec^{-1} (1 Å/sec) and 10^{-6} g cm^{-2} sec^{-1} (30 Å/sec) no change of τ_{ex} was observed, accurate to 8 and 25% respectively. Therefore the time of contamination of the clean surface by a sufficient amount of impurities that could, in principle, heat the UCN should be less than 0.1 sec.

4. When UCN are stored, two independent competing processes lead to the loss of UCN from the vessel: $\tau_{ex}=\tau_\beta^{-1}+\tau_{ie}^{-1}$, where $\tau_\beta=940$ sec is the β-decay constant of the free neutron and τ_{ie} is the containment time governed by the inelastic interactions of the UCN with the wall (heating and capture). If the average frequency of the UCN impacts against the walls is ν and the average loss coefficient in one collision is $\bar{\mu}$, then $\tau_{ie}^{-1}=\bar{\mu}\nu$. Taking gravitation into account[8] we have:

$$\nu=\frac{\int_{(s)} nv^{\bullet}ds}{4\int_{(v)} n\,dv}\,,\ \text{and}\ \bar{\mu}=\frac{\int_{(s)}\mu(v^{\bullet})\,n\,v^{\bullet}ds}{\int_{(s)} nv^{\bullet}ds}\,,$$

where n is the density of the UCN gas (Fig. 1b), and v' is the UCN velocity at the corresponding height. In our case $\nu \propto v_0^{-1}$ (v_0 is the velocity at the level of the vessel bottom), at an average spectrum velocity $\nu \sim 6.3\ \text{sec}^{-1}$, $\bar{\mu}$ depends on the concrete inelastic process in question. If account is taken of only the known cross sections of capture and inelastic scattering by the wall material, the values of the containment time (τ_{th}) are 4–100 times larger than those obtained from experiment.

5. We note that at $v_0 \ll v_{\text{lim}}$, in first order approximation, $\mu(v) \approx 4/3 \eta v_{\text{gr}}^{-1}$, for any inelastic process, where the dimensionless coefficient η equals, in accord with the standard definition, $\eta = \text{Im} b_{\text{eff}} b^{-1}$.[5] Introducing the geometric factor κ of the experiment, which in our case is independent in first-order approximation of the UCN spectrum and of the mechanism by which they leak out of the vessel, we can write $\tau_{ie}^{-1} = \eta\kappa$. Figure 2(a) shows an approximately linear dependence of $\tau_{ex}^{-1} - \tau_{th}^{-1}$ on κb^{-1}.

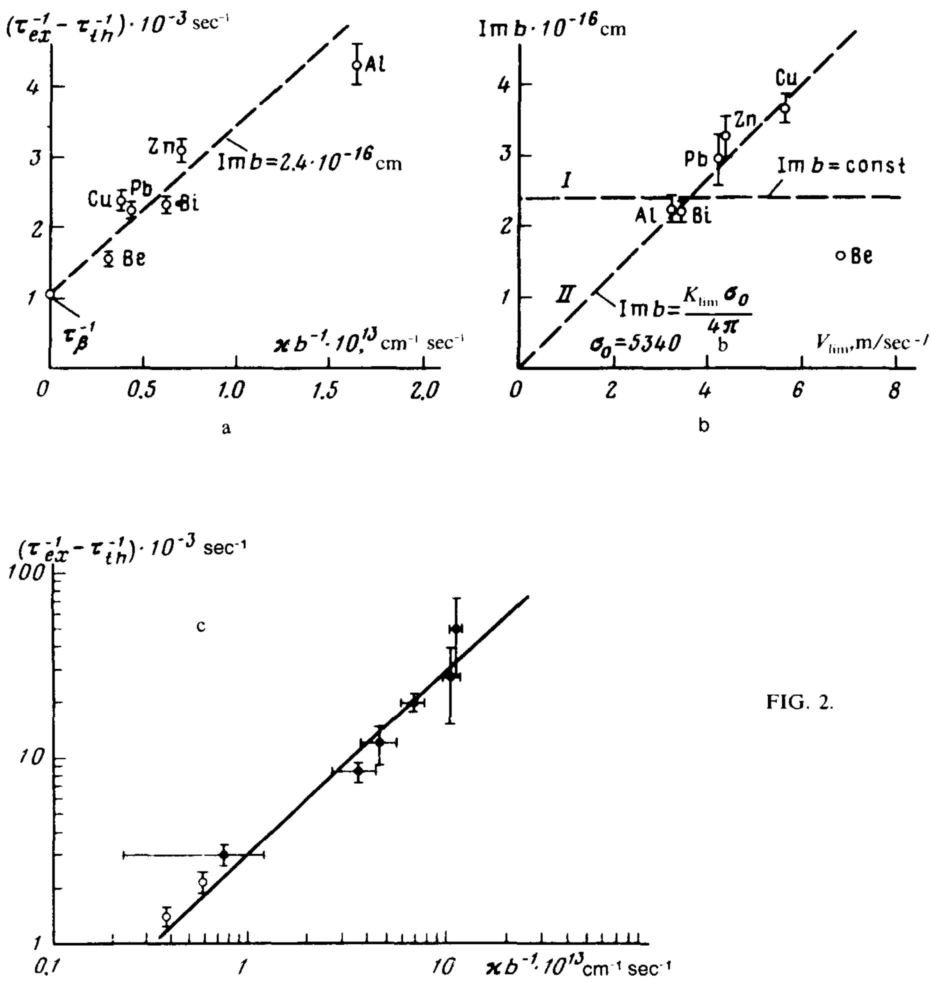

FIG. 2.

A more detailed structure of this dependence is shown in Fig. 2(b), where the anomalous part $\mathrm{Im} b_{\mathrm{eff}}$ is plotted against v_{lim}. We can consider two extreme locations of the anomalous leakage: I) in a layer on the order of the depth of penetration of the neutron into the wall, when $\mathrm{Im} b = k\sigma(k)/4\pi$,[11] and consequently the additional cross section amounts to ~ 8 b when recalculated in terms of the thermal-neutron energy; II) in a layer of thickness much smaller than the neutron penetration depth, when $\mathrm{Im} b \propto v_{\mathrm{lim}}$[9] and we can use the phenomenological expression $\mathrm{Im} b = k_{\mathrm{lim}}\sigma_0/4\pi$.[10]

6. The value $\eta = 6\times 10^{-4}$ obtained for Cu differs from the results $\eta = 3.7\times 10^{-4}$ of the only study[12] for which the spectrum of the stored neutrons is well known. Our value of σ_0, however, coincides with the value that can be calculated from[12] (Fig. 2c).

Figure 2(c) shows the dependence of the anomalous leakage of UCN from copper vessels on κb^{-1}, with κ calculated under assumption II of Sec. 5. The filled circles show the results calculated from the data of[12].

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[1]L.V. Groshev, V.N. Dvoretskiĭ, A.M. Demidov, V.I. Lushchikov, Yu. N. Panin, Yu. N. Pokotilovskiĭ, A.V. Strelkov, and F.L. Shapiro, JINR R3-5392, Dubna, 1970; Phys. Lett. **36B**, 293 (1971).
[2]A.I. Egorov, V.M. Lobashov, V.A. Nazarenko, G.D. Porsev, and A.P. Serebrov, Yad. Fiz. **19**, 300 (1974) [Sov. J. Nucl. Phys. **19**, 147 (1974)].
[3]A. Steyerl and W.-D. Trüstedt, Z. Physik **267**, 379 (1974).
[4]Yu. Yu. Kosvintsev, E.N. Kulagin, Yu. A. Kuschnir, V.I. Morozov, and A.V. Strelkov, Nucl. Instr. and Methods **143**, 132 (1977).
[5]F.L. Shapiro, JINR R3-7135, Dubna, 1973; Conf. on Nuclear Structures Study with Neutrons, Budapest, 1972, Plenum, 1975, p. 259.
[6]A.V. Strelkov and M. Hetzlt, Zh. Eksp. Teor. Fiz. **74**, 23 (1978) [Sov. Phys. JETP **47**, No. 1 (1978)].
[7]W.A. Lanford and R. Golub, Phys. Rev. Lett. **39**, 1509 (1977).
[8]V.K. Ignatovich and G.I. Terekhov, JINR, R4-9567, Dubna, 1976.
[9]V.K. Ignatovich and A.V. Stepanov, JINR R4-7832, Dubna, 1974.
[10]I.M. Frank, JINR, R3-7810, Dubna, 1974.
[11]V.K. Ignatovich and L.M. Satarov, IAE-3230, Moscow, 1977.
[12]L.V. Groshev, V.I. Lushchikov, S.A. Nikolaev, Yu. N. Panin, Yu. N. Pokotilovskiĭ, and A.V. Strelkov, JINR R3-9534, Dubna, 1976.