Anomalous interaction of ultracold neutrons with the surface of a beryllium trap

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The temperature dependence of the cross section for the interaction of ultracold neutrons with Be has been studied experimentally. A difference has been found between the cross sections for the neutron-Be interaction at the surface of the material and in its interior. This difference is $\simeq 0.9$ b. The corresponding value of the loss factor is 3×10^{-5} per reflection from the surface.

The interaction of ultracold neutrons with the surfaces of beryllium traps has been studied in connection with the problem of measuring the lifetime of the neutron.[1] It has been suggested that the well-known problem in achieving prolonged confinement of ultracold neutrons which stems from the inelastic scattering of these particles

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by the surface of the trap, because of hydrogen compounds,[2] might be solved by first degassing the traps in vacuum at 700 K and then cooling them to a low temperature (10–15 K) during the measurements. Theoretically, the loss of ultracold neutrons during confinement in a beryllium trap at 10–15 K could be reduced to a level much lower than 1% of the probability for β decay of the neutron. This conclusion is indicated by a direct experiment in which the temperature dependence of the total cross section for the interaction of very cold neutrons (8–15 m/s) with Be was measured as the neutrons passed through beryllium samples[3] (Fig. 1; the experimental data are shown by points 1a, 2a, and 3a). The theoretical dependence of the cross section for the loss (heating plus capture) of ultracold neutrons in Be (curve 1b) gives a fairly good description of the experimental results on the transmission of very cold neutrons, within the scattering by structural irregularities ($\simeq$0.1 b).

However, in the course of the measurements with the beryllium trap it was found that the probability for the loss of ultracold neutrons during confinement at low temperatures amounted to 5–6% of the probability for β decay of the neutron. It also turned out to be independent of the particular method used to fabricate the trap and furthermore independent of how carefully the surface was cleaned. The results found in measurements of the temperature dependence of the total cross section for the loss of ultracold neutrons as they interacted with the surface of beryllium traps, for various

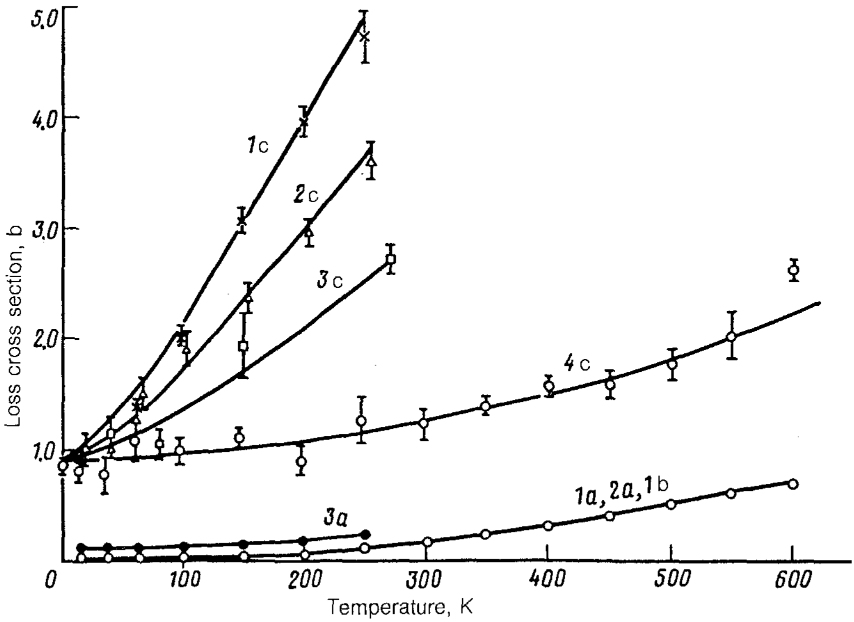

FIG. 1. 1a—Fused Be; 2a—quasi-single-crystal Be; 3a—pressed sintered beryllium; 1b—theoretical temperature dependence of the beryllium loss cross section ($\sigma_a + \sigma_{in}$) calculated in the Debye model; 1c—"spherical" deposited Be trap, not degassed; 2c—deposited cylindrical trap, degassed (5 h at 250 °C); 3c—all-Be trap, degassed (8 h at 300 °C); 4c—"spherical" deposited trap, degassed (28 h at 350 °C, with purification of the evaporated He and D_2).

degrees of cleanliness of the traps, are shown in Fig. 1 (curves 1c, 2c, 3c, and 4c). One of the traps (curve 3c) was made of metallic Be; the other traps had a deposited beryllium coating. An important point is that at low temperatures all the curves converge on a single point, 0.9 b. This value does not correspond to the cross section for the interaction of very cold neutrons in the interior of the material. For the trap which was degassed and cleaned most thoroughly (curve 4c), the temperature dependence reproduces the shape of the calculated dependence of the cross section for inelastic scattering for Be, but the cross sections are higher than the calculated values by $\simeq 0.9$ b over the entire temperature range down to 10 K. At 6.5 K, the cross section for the loss of ultracold neutrons during confinement does not change, according to the data of Ref. 4. The temperature dependence of the observed effect indicates that the effect could not be a consequence of inelastic scattering. Nevertheless, to carry out a more detailed analysis of this situation, we turned to some measurements of the inelastic scattering of ultracold neutrons by a degassed beryllium foil, using the method of detecting heated neutrons.[5] The results, converted into the temperature dependence of the heating cross section, are shown in Fig. 2. We see that at a temperature of 80 K the neutron heating due to impurities containing hydrogen has already decayed below the level of 140 mb and could not explain the observed effect. Attempts to explain this effect on the basis of nuclear capture by hydrogen also fail, since the hydrogen capture cross section is 0.33 b, clearly insufficient at the hydrogen concentration observed at the surface.

We used x-ray fluorescence analysis to check the possibility of a contamination by strongly absorbing elements in the case of the deposited Be. The surfaces of samples cut from an all-beryllium trap were studied to a depth $\simeq 20\ \mu$m on an electrostatic

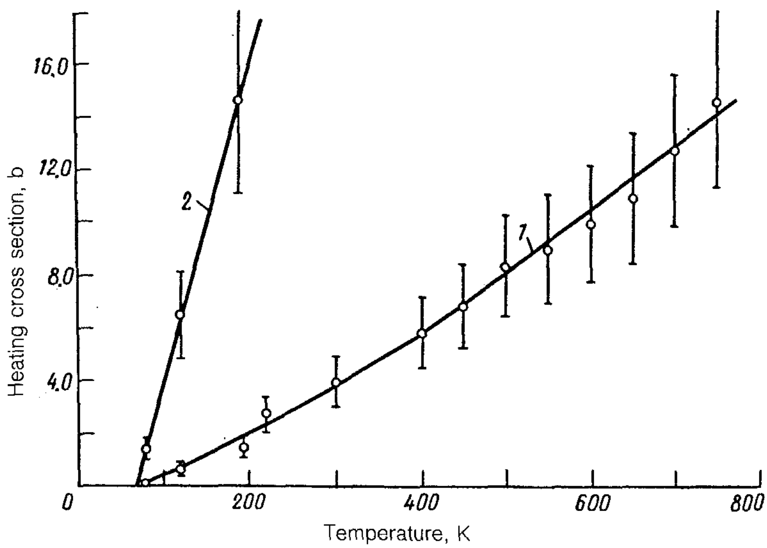

FIG. 2. 1—Temperature dependence of the cross section for the heating of ultracold neutrons at a degassed Be foil; 2—the first three points of this dependence, drawn to an ordinate scale larger by a factor of 10.

accelerator by a method involving recording the proton-induced x-ray fluorescence. The contaminants which were found contributed 23.64 mb to the neutron capture cross section in the case of the deposited Be and 12.63 mb for the all-metal trap. The contamination of the deposited surface with light elements (nitrogen and boron) was studied in the reactions $^{14}N + n = {}^{14}C + p$ and $^{10}B + n = {}^{7}Li + \alpha$ in a beam of cold neutrons. The nitrogen content in the surface was less than 4×10^{15} atom/cm^2, while a content of 5.5×10^{16} atom/cm^2 would be required in order to explain the observed effect. The boron content was $(4 \pm 1.5)\times 10^{12}$ atom/cm^2, while 4.3×10^{14} atom/cm^2 would have been needed.

We did not observe any "milliheating" of the ultracold neutrons due to vibrations of the apparatus. The hypothetical possibility of an anomalous transmission of below-barrier neutrons through the 200-μm vacuum-tight beryllium foil was studied in a special experiment. No ultracold neutrons, above the level of 6×10^{-6}, were found to tunnel through the foil. The effect which would be needed to explain the observed confinement time of ultracold neutrons in the beryllium trap is at the level of 3×10^{-5}.

The mechanism of an increase in the loss factor due to, for example, an increase in the surface roughness[6,7] is contradicted by the shape of the experimentally observed temperature dependence of the loss cross section.

In summary, the discrepancy found here cannot be explained on the basis of the existing ideas regarding the interaction of ultracold neutrons with matter.

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