Quantum effects occurring when ultracold neutrons are stored on a plane

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The problem of storing ultracold neutrons (UCN) on a plane in the presence of a gravitational field is considered. The energy of the vertical motion is then quantized, and the wave functions of the first states are localized in space. The energy and linear dimensional constants of the problems are $\epsilon = 0.6\times10^{-12}$ eV and $\lambda = 0.3\times10^{-3}$ cm. A method is proposed for experimentally separating neutrons situated on the first energy level. Attention is called to the fact that an inhomogeneous magnetic field can be used to vary the values of ϵ and λ in a rather wide range.

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The discovery of ultracold neutrons (UCN) has made accessible for study a new region of very low enegies of elementary particles. Workers with UCN are now accustomed to energies $\sim 10^{-8}$ eV. One can expect to obtain in the near future sources of UCN with substantially higher intensity than at present, so that it will become possible to work with even "colder" neutrons. On going to still lower energies, quantum effects can come into play in macroscopic objects. In this connection it is possible, in particular, to consider the well known problem of a particle that is elastically reflected from a horizontal plane and in a potential $U = Fz$ (Fig. 1). The energy of the vertical motion

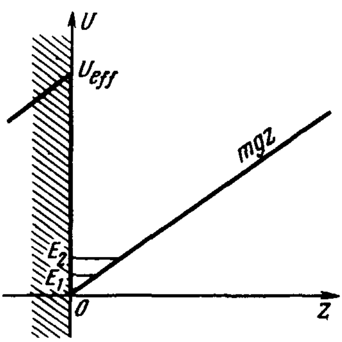

FIG. 1. Effective potential in the reflection of UCN from the horizontal plane, $E_1 = 1.4\times10^{-12}$ eV, $E_2 = 2.45\times10^{-12}$ eV.

is then quantized, and the wave functions of the levels are Airy functions.[1,2] The problem is characterized by an energy constant $\epsilon = [(\hbar F)^2/2m]^{1/3}$ and by a linear dimensional constant $l = (h^2/2mF)^{1/3}$. For a neutron on a plane in a gravitational field ($F = mg$) these constants are $\epsilon = 0.6\times10^{-12}$ eV and $l = 0.3\times10^{-3}$ cm. The level positions are determined by the relation $E_n = \lambda_n \epsilon$, where λ are the zeros of the Airy functions. The first two levels have energies 1.4×10^{-12} and 2.45×10^{-12} eV. A very close result can be obtained by combining the classical expression $H = v^2/2g$(H is the height

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to which the neutron rises over the surface) with the quantum-mechanical requirement $H \gtrsim \lambda, v^2/2g \gtrsim 2h/mv$, whence $v \gtrsim 2.4$ cm/sec, $H \sim 0.003$ cm, and $E = mv^2/2 \sim 3\times10^{-12}$ eV. It was also pointed out in Ref. 3 that the wave function of the first level is localized near the plane in a region having much smaller dimensions than for the second level (19 and 28 μm, respectively). This makes it possible in principle to separate experimentally neutrons located only on the first level.

If a UCN beam is passed through a slit of height $\sim 20\ \mu$m, made up of a horizontal reflecting surface and an absorber, with zero limiting velocity (Fig. 2), then the

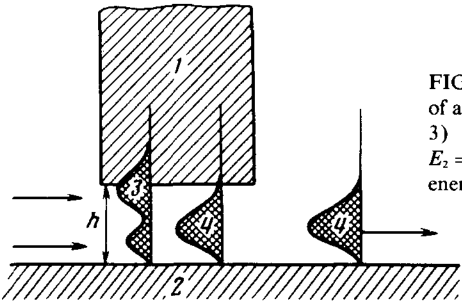

FIG. 2. "Flow" of UCN over a horizontal surface in the case of a gravitational potential. 1) absorber, 2) reflecting surface, 3) density of UCN with vetical-motion energy $E_2 = 2.45\times10^{-12}$ eV. 4) Density of UCN with vertical-motion energy $E_1 = 1.4\times10^{-12}$. Height of slit $h \approx 20\ \mu$m.

neutrons with energy E_1 will be passed by such a system. These neturons will flow (or "glide") over the surface without being detached from it (no limitation is imposed on the tangential component of the velocity), even if the surface deviates from horizontal, inasmuch as the transition to the next level calls for a finite energy increment. The flux of such neutrons is approximately 10^{-3} of the total flux and is not hopelessly small for experiments.

The magnitude of the effect can be influenced by placing the system in an inhomogeneous magnetic field ($F = mg \pm \mu(\partial B/\partial z)$), where μ is the magnetic moment of the neutron.

Choosing the required value of the magnetic field in the neutron polarization direction, we can alter the value of F in a wide range. By compensating for the gravitation ($F < mg$) we can increase l ($l \sim F^{-1/3}$), making more pronounced the described surface flow of the UCN. On the other hand, if F is increased by using a strongly inhomogeneous field, the value of ϵ can be noticably increased. For the perfectly attainable field inhomogeneity $\partial B/\partial z = 5\times10^4$ G/cm, we obtain $F = \mu(\partial B/\partial z) \sim 3\times10^{-7}$ eV/cm ($mg \approx 1\times10^{-9}$ eV/cm). In this case $\epsilon = 1.2\times10^{-10}$ eV, and the first two levels are located at 2.8×10^{-10} and 4.9×10^{-10} eV, i.e., in a region already accessible to spectrometry. The question of the lifetime of the neutron in such a system is worthy of attention. In the classical case at $v < v_{gr}$ the lifetime of the neutron on a plane in a gravitational field is given by[4] $\tau = v_{gr}/g\eta$, where η is the ratio of the imaginary and real parts of the wall potential. For the usual values $v_{gr} = 500$ cm/sec and $\eta = 1\times10^{-4}$ we get $\tau = 5\times10^3$ sec, which is more than the half-life of the neutron $\tau_0 \approx 10^3$ sec. Our case is equivalent to replacing g by the quantity F/m. Thus, a classical estimate yields for the neutron lifetime in such a system a value $\tau \sim 20$ sec and a level width 3×10^{-17} eV. When the neturon moves over the plane it can become inelastically scattered by the roughnesses of the surface. In this case a neutron with a horizontal velocity component perceives the references as an oscillating surface. Estimates show that the probability of such a scattering is $\sim 10^{-3}$ sec^{-1}.

We wish to note that in experiments with magnetic potentials it is possible to alter the magnetic induction during the neutron storage time, thereby investigating the nonstationary picture.

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