Search for long-range forces of a neutron and atoms with a trap of ultracold neutrons

A.P. Serebrov, O.M. Zherebtsov, S.V. Sbitnev

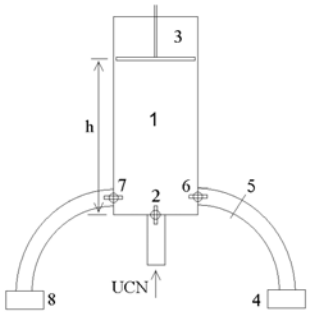
Petersburg Nuclear Physics Institute, Russian Academy of Sciences, Gatchina, Russia

Introduction

A new method suggest using gas of ultracold neutrons (UCN) as a target that is collided with the flux of atom. Criterion of a signal of scattering cased by long-range forces is transfer of ultimately small recoil energy about 10^{-7} eV

Experimental setup

UCN fill the trap at the opened valve (2) and at pulled down absorber (3). When the equilibrium density in a trap (1) has been achieved, the valve (2) is closed, the absorber (3) is pulled up. While storage in the trap, UCN interact with walls and investigated gas. The neutrons which have obtained a small recoil energy can be still stored in the trap, but they can overcome a potential barrier of the foil (5) and can be registered by the detector (4).

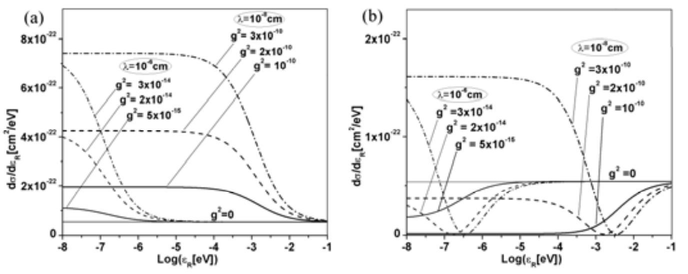


The experiment setup: 1 – trap of UCN, 2 – the input valve, 3 – the absorber-former of spectrum of UCN, 4 – the detector of lower barrier neutrons, 5 – a foil with the boundary velocity above the one of UCN after spectrum formation, 6 – the valve for the background measurement with the detector of upper barrier neutrons, 7 – the valve for output of UCN after storage, 8 – the detector for counting of UCN after storage

Numerical calculations and estimations

The differential cross section of scattering of a neutron with an atom should take into account the amplitude of nuclear scattering and that of scattering due to an additional contribution from the long-range potential

$$\varphi = \frac{\pm g_{\pm}^2 M\hbar c\, e^{-r/\lambda}}{4\pi r} \qquad f_{long\_range} = \frac{\mp 2m}{\hbar^2}\frac{g_{\pm}^2 M\hbar c}{4\pi}\frac{\lambda^2}{(\lambda q)^2+1}$$



Dependence of the differential cross section on the recoil energy transferred to a neutron for various values of λ. (a) the case of a repulsive potential, (b) the case of an attractive potential

A. Measuring of integrated cross section

The probability of UCN losses due to collision with atoms of the gas can be written as follows:

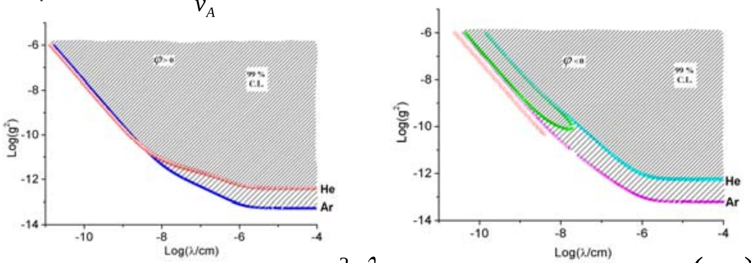
$$\tau_{stor}^{-1} = \int_{E_{min}}^{\infty} dE_A \Phi(E_A) \int_{\varepsilon_{min}}^{E_A \frac{4M}{(M+1)^2}} d\sigma(\varepsilon)$$

A flux of atoms is $\Phi(E_A) = \frac{4\rho}{kT}\left(\frac{1}{2\pi m_n MkT}\right)^{1/2} E_A \exp\left\{-\frac{E_A}{kT}\right\}$

$$(\rho\tau)^{-1} = 4\left(\frac{1}{2\pi m_n MkT}\right)^{1/2} \int_{E_{UCN}}^{\infty} dE_A \int_{E_{UCN}}^{E_A\frac{4M}{(M+1)^2}} \frac{E_A}{kT} e^{-E_A/kT} \frac{\pi (M+1)^2}{M} b_{free}^2 \times \left|1-\frac{f_{long\ range}}{b_{free}}\right|^2 \frac{d\varepsilon}{E_A}$$

Constraints on the parameter $g^2(\lambda)$ are obtained from difference $\Delta = \left[\frac{\sigma_{p\tau}^A}{4\pi b_{free}^2} e^{\frac{E_{UCN}}{kT}\frac{(M+1)^2}{4M}} - 1\right]$

$$\sigma_{p\tau}^A = \frac{(p\tau\cdot 2.69\cdot 10^{16})^{-1} - \sigma_a^A \bar{v}_{th}}{\bar{v}_A}$$

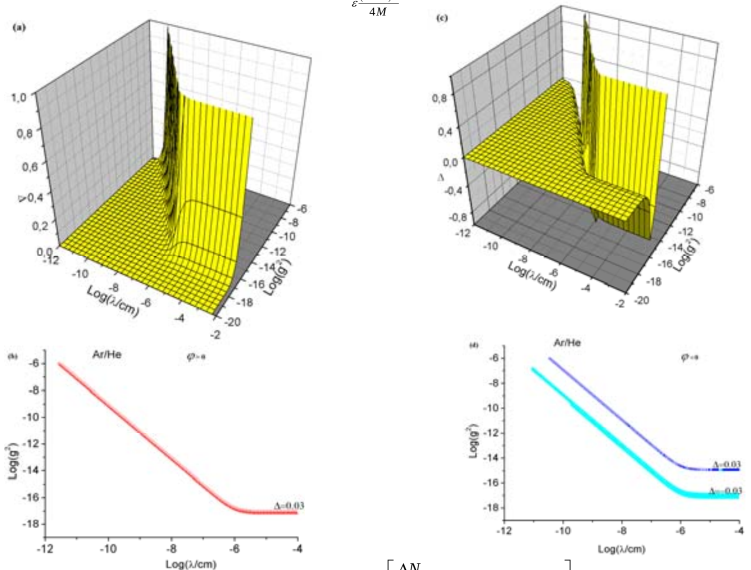


Areas of the constraints on g^2, λ from the experimental data $(p\tau)$ for argon and helium . left is the case of a repulsive potential, right is the case of an attractive potential.

B. The method of measuring the flux of above-barrier neutrons

One can measure the quantity of UCN heated within the interval of energies from $\varepsilon_1 \approx E_{UCN}^{foil}$ to $\varepsilon_2 \approx E_{UCN}^{trap}$

$$\frac{\Delta N}{\Delta t} \approx \int_{\varepsilon_1}^{\varepsilon_2} \mathrm{E}(\varepsilon) \int_{\varepsilon\frac{(M+1)^2}{4M}}^{\infty} \frac{d\sigma}{d\varepsilon}(\varepsilon)\Phi(E_A)\,dE_A\,d\varepsilon$$



Magnitude of possible effect $\Delta \equiv \left[\frac{\frac{\Delta N_{Ar}}{\Delta t}}{\frac{\Delta N_{He}}{\Delta t}} \frac{\rho_{He} b_{bound}^{He^2}\sqrt{M_{He}}}{\rho_{Ar} b_{bound}^{Ar^2}\sqrt{M_{Ar}}} - 1\right]$ *- (a),(c).*

(b),(d) are values of $g^2(\lambda)$ *at* $|\Delta| = 0.03$