Direct Measurement of the Neutron Velocity in a Refractive Medium and Test of the Dispersion Law for UCN

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It is well known that the dispersion law of slow neutrons in matter is described with high accuracy by the ratio [1]

$$k^2 = k_0^2 - 4\pi\rho b, \tag{1}$$

where k is the wave number in the medium, k_0 is the wave number in vacuum, ρ is the number of nuclei per unit volume, and b is the coherent scattering length. This dependence corresponds to the effective potential, $U = \left(2\pi\hbar^2/m\right)\rho b,$ where m is the neutron mass. For this reason, dispersion law (1) is often referred to as a potential law. From formula (1) it follows directly that the refractive index of a neutron in a medium is determined as

$$n(k) = \left[1 - \left(4\pi\rho b/k_0^2\right)\right]^{1/2}. \tag{2}$$

For a long time, it was considered obvious that from the fact of the existence of a refractive index different from unity, it directly follows that the speed of a neutron in a matter is $V=nV_0$. In fact, the refractive index $n=k/k_0$ is the ratio of wave numbers in a vacuum and a medium, and not the ratio of velocities V/V_0. As to the neutron speed in the medium it is determined by the quantity $V = \frac{\hbar k}{m^*}$, where m is the effective mass of the neutron in the medium, the value of which depends on the dispersion law. It is equal to the inertial mass of the neutron only in the case of the potential dispersion law [2].

The difference between the speed of neutrons in a refractive medium and the vacuum value was first demonstrated in a direct experiment [3], which consisted of measuring the precession phase of the spin of neutrons passing through samples of various thicknesses. The relatively low accuracy of these measurements, about 10%, did not allow us to draw any significant conclusions about the neutron dispersion law in the medium.

This report is devoted to the proposal of an experiment to directly measure the speed of ultracold neutrons in a refractive medium with percentage accuracy. The experimental approach consists of measuring the time delay in the time of flight of the UCN, caused by the presence of a refractive sample neutron on its path. Measuring the time delay for neutrons with a well-known and variable energy will make it possible to verify the dispersion law of UCNs in matter with an accuracy of the order of a percent.

References

1. L.L. Foldy. Phys. Rev **67**, 107 (1945), M. Lax. Rev. Mod. Phys. **23,** 287 (1951).
2. A.I. Frank. Physics-Uspekhi, **61**, 900 (2018).
3. A.I. Frank, I.V. Bondarenko, A.V. Kozlov, et.al. Physica B: Cond. Matter **297**, 307 (2001).