Comment on "Precision Neutron Interferometric Search for Evidence of Nuclear Quantum Entanglement in Liquid H_2O-D_2O Mixtures"

In a recent Letter, Ioffe *et al.* [1] reported about the measurement of the coherent scattering length density (Nb) of liquid H_2O-D_2O mixtures at room temperature, using a high precision technique of neutron interferometry (NI). The data analysis shows, in essence, that there is no deviation of the measured *Nb* values from those conventionally calculated on the basis of simple random mixing of two liquids [see Eq. (1) of [1]]. These findings are fully consistent with conventional theory.

Furthermore, it is claimed that "These results are not consistent with the predicted deviations due to quantum entanglement between protons and deuterons, …" (cf. the abstract of [1]). In this context, our deep-inelastic neutron scattering (DINS) results [2] are cited, together with some unpublished NI and neutron reflectivity (NR) preliminary work; see below. As a consequence, the impression arises that the NI results of [1] can be interpreted as being in conflict with our DINS results and the theoretical investigations concerning *short-time* quantum correlations cited in our Letter [2]. However, such a "conflict" does not exist, as is explained in the following.

As a matter of fact, the relevant physical conditions of the (inelastic and incoherent [3]) DINS method differ significantly from those of the (elastic and coherent) NI technique. It is essential to note that the *characteristic time window* (or "scattering time") Δt_{DINS} of DINS—as given by the energy and momentum transfers of the eVS instrument of the ISIS facility, cf. [2,4]—lies in the subfemtosecond time range. This fact has been pointed out in [2], where also a rough estimate of Δt_{DINS} was given. Recently [4], we investigated the effect of [2] in the metal hydride Nb-H-D, where also Δt_{DINS} has been considered in more detail (i.e., according to [3]) and was found to be in the subfemtosecond regime.

In clear contrast, the characteristic time-window Δt_{NI} of the NI technique (which here may be called "traversal time"; see [5]) is many orders of magnitude larger than Δt_{DINS}. For illustration, the following simple estimation is given: The neutrons used in [1] have a de Broglie wavelength of ca. 2.7 Å, thus having a velocity of ca. 1500 m/s. The used cuvettes were ca. 0.2 and 3 mm thick [1], which implies that the traversal time [5] of the neutrons through the liquid samples are of the order of a microsecond. The NI method (representing elastic coherent scattering in the forward direction) determines the average value of *Nb* of the whole sample, and therefore it should be characterized by the time window $\Delta t_{\mathrm{NI}} = 10^{-6}$ s. In other words,

$$\Delta t_{\mathrm{DINS}} \leq 10^{-9} \Delta t_{\mathrm{NI}}\,, \tag{1}$$

which proves the aforementioned statement. In simple terms, the "slow" NI technique is by no means able to detect the short-time correlations being revealed with the "fast" DINS techniques.

As concerns the definition of "scattering time" (or "interaction time"), in the case of DINS it is given by Sears and by Watson [3]. In the case of NI, one could disagree with the preceding estimation and, instead, consider as the relevant Δt_{NI} the time needed by the wave packet of the neutron to "pass" over two (entangled) protons. Another possibility would be to refer to the energy-time uncertainty relation, in connection with the neutron beam monochromaticity, and infer a numerical value for Δt_{NI}. Rough estimations of these possible "alternative" interaction times yield values of Δt_{NI} being smaller than that of Eq. (1), but still many (say, 4 or 5) orders of magnitude larger than Δt_{DINS}. We believe that these alternative definitions of Δt_{NI} are physically incorrect. Note, however, that $\Delta t_{\mathrm{DINS}} \ll \Delta t_{\mathrm{NI}}$ still holds.

Reference [1] mentions "predictions of quantum entanglement (QE)" allegedly presented in our preliminary short NI and NR experimental reports (Refs. [3,4] of [1]) and in the publications [7] (i.e., Ref. [2] of [1]) which the NI results contradict. This is not correct. In the unpublished reports, as well as in our published NR work [6], connection with QE is only hinted at. Moreover, in [7] the topics of NI and/or NR are not even mentioned.

In summary, we conclude that the Letter [1] can neither falsify nor verify the existence of short-time quantum correlations [2] because NI operates at a considerably longer time window.

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