# How to Search for $\eta$-Mesic Nuclei

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The existence of $\eta$-mesic nucleus, a bound state of $\eta$ meson in a nucleus, is a natural consequence of the attraction between the $\eta$ meson and the nucleon at very low energies[1]. However, the attraction is not strong enougth to bind an $\eta$ onto a single nucleon. But, the bound state formation is possible in finite nuclei[2]. The $\eta$-mesic nuclei are due to strong-interaction force, which makes them distinct from mesic atoms which are caused by the Coulomb force. The $\eta$-mesic nuclei, if they exist, would provide an opportunity to study nuclei having an excitation energy of $\sim$ 540 MeV (to be compared with an excitation energy of $\sim$ 200 MeV associated with the hypernuclei). Since the $\eta N$ scattering is not directly measurable, different theoretical models and fits to various data have yielded very different $\eta N$ scattering lengths. Using the stronger ones, many researchers predict that $\eta$ can be bound onto nuclei as light as $^3$He. However, these predictions are based upon using the free-space $\eta N$ interaction, in marked contrast to covariant calculations[2] which indicated that the bound-state formation would occur in nuclei only with $A > 11$. Because the $\eta$-mesic nucleus remains elusive at this time, we will address the problem of how to look for these nuclei.

We first demonstrate that the in-medium $\eta N$ interaction occurs at $\sim$30 MeV below the $\eta N$ threshold. Hence, the in-medium interaction is necessarily much weaker (typically by $\sim$ 20 to 33%, depending on the specific $\eta N$ off-shell model). We have also noted that, in the literature, the final-state-interaction (FSI) analysis was applied to $pd \rightarrow \eta^3$He and $dd \rightarrow \eta^4$He reactions. From those analyses the possibility of having $\eta-^{3,4}$He bound states was articulated[3,4]. We will demonstrate that the FSI analysis cannot unambiguously determine whether there is necessarily a bound state of the $\eta$.

We suggest, therefore: (a) avoiding searches in very light nuclei, as suggested by calculations based on the use of free-space $\eta$-nucleon scattering lengths; and (b) carrying out coincidence measurements to determine if the particles detected are the decay products of an $\eta$-nucleus bound states. Although these measurements require more resources, the experiemental signal, if seen, will be unambiguous.

## References

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