Comment on "Nuclear-Bound Quarkonium"

Brodsky, Schmidt, and de Téramond have recently examined the interesting question of whether heavy-quarkonium states, in particular charmonium, bind to nuclear matter [1]. They find that charmonium binds to nuclei with $A=3$ and higher with a binding energy that increases with A. By $A=9$ they find bindings as large as 400 MeV. Estimates of the size of the binding are important for determining the feasibility of experiments designed to observe this effect. In this Comment, I argue that the form of the effective charmonium-nucleus potential differs from what they assume and as a consequence, the binding does not increase strongly with A and instead reaches a maximum value of ~ 30 MeV.

Assume as Brodsky, Schmidt, and de Téramond do that the effective charmonium-nucleon potential is of the Yukawa form

$$V_{(\bar{c}c)N}(r) = -(\alpha/r)\exp(-\mu r). \tag{1}$$

The parameters of this potential are estimated to be $\alpha=0.4$–0.6 and $\mu=0.6$ GeV [1]. This potential is not strong enough to bind the charmonium to the nucleon. Nonetheless it is purely attractive so one expects binding to heavier nuclear systems.

Since the range of the nucleon-charmonium potential (~ 0.3 fm) is short compared to the radius of a nucleus, the precise form of the charmonium-nucleus potential is very dependent on the distribution of nucleons in the nucleus. At low energies one can estimate the charmonium-nucleus potential $V_{(\bar{c}c)A}$ as

$$V_{(\bar{c}c)A}(r) = \int d^3r'\, V_{(\bar{c}c)N}(r-r')\rho_A(r'), \tag{2}$$

where $\rho_A(r)$ is the nucleon distribution in the nucleus and A is the atomic number $[\int d^3r\, \rho_A(r) = A]$. Equation (2) assumes that the structure of the nucleus is unchanged by the relatively weak interaction of the nucleons with the charmonium and that charmonium-nucleon many-body forces are not important.

In nuclear matter, $\rho(r) = \rho_{\rm NM} \sim 0.17\ {\rm fm}^{-3}$ and the charmonium–nuclear-matter potential ($V_{(\bar{c}c)\rm NM}$) is given by $V_{(\bar{c}c)\rm NM} = \rho_{\rm NM}\int d^3r\, V_{(\bar{c}c)N}(r) \sim -30$ MeV, where the numerical value is for $\alpha=0.6$ and $\mu=0.6$ GeV. Finite nuclei generally have a uniform interior and a surface of thickness ~ 1 fm. Consequently, as the size of the nucleus increases the charmonium-nucleus potential interpolates between the Yukawa form of Eq. (1) and the nuclear-matter value. Specific examples are shown in Fig. 1, where the results of performing the integral in Eq. (2) for realistic nucleon densities [2] are displayed. The shapes of the potentials differ significantly from the Yukawa shapes assumed in Ref. [1]. As A increases, the range of the potential increases, but the depth stabilizes at the nuclear-matter value, implying that the binding energy is ≤ 30 MeV for all A.

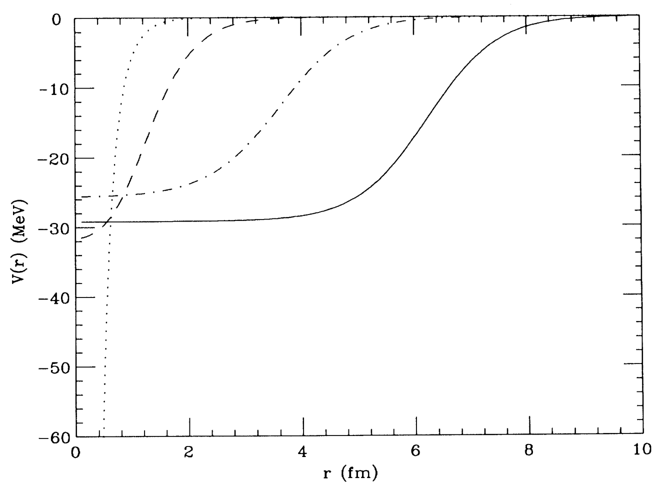

FIG. 1. Effective charmonium-nucleus potentials for various A. The dotted line is the $A=1$ result given by Eq. (1) and the dashed line is the $A=4$, the dash-dotted line is the $A=40$, and the solid line is the $A=200$ results predicted by Eq. (2).

This is verified by numerically solving the Schrödinger equation for the charmonium-nucleus system using the potentials generated by Eq. (2). The results are no binding for $A=1,2$ and ground-state binding energies (and rms radii) of 0.8 MeV (3.5 fm) for $A=3$, 5.0 MeV (1.9 fm) for $A=4$, 13.5 MeV (1.7 fm) for $A=12$, 19 MeV (2.0 fm) for $A=40$, and 27 MeV (3.1 fm) for $A=200$. Although the size of the binding calculated here is much smaller than Ref. [1], we agree that there is binding to nuclei with $A \geq 3$ and that the detection of such states would be very interesting.

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