

Enhanced binding and cold compression of nuclei due to admixture of antibaryons

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We discuss the possibility of producing a new kind of nuclear systems by putting an antibaryon inside ordinary nuclei. Unlike the works of other authors, we take into account strong polarization of the target nucleus due to presence of an antibaryon. The ground state structure of such systems is calculated within the relativistic mean-field model assuming that the nucleon and antinucleon potentials are related by the G-parity transformation. We use three different versions of this model, TM1 [1], NL3 and NL-Z2 [2], with parameters found by fitting binding energies and charge form factors of spherical nuclei from ^{16}O to ^{208}Pb . In the present paper we consider two nuclear systems, namely ^{16}O and ^8Be , with an antiproton in the lowest bound state.

Following the procedure suggested in Ref. [3] and assuming the axial symmetry of the nuclear system, we solve effective Schrödinger equations for nucleons and antiproton together with differential equations for mean meson and Coulomb fields. We explicitly take into account the antiproton contributions to the scalar and vector densities. The antiproton gives a negative contribution to vector density, but increases the local scalar density. This leads to increase of attraction and decrease of repulsion for surrounding nucleons. To maximize attraction, nucleons move to the center of the nucleus, where the antiproton has its largest occupation probability. This gives rise to strong compression of the nucleus and causes dramatic rearrangement of its structure.

The calculation shows that inserting an antiproton inside the ^{16}O nucleus leads to increase of maximum nucleon density by a factor 2–4 depending on the parametrization. Deeper nucleon potentials give rise to increased nuclear binding. As compared to 130 MeV binding energy of ^{16}O , its value for ^{16}O with an antiproton is 830, 1050 and 1160 MeV for the NL-Z2, NL3 and TM1, respectively. Due to this anomalous binding we call these systems super bound nuclei (SBN).

As a second example, we investigate the effect of a single antiproton inserted into the ^8Be nucleus. The normal ^8Be nucleus is not spherical, exhibiting a clearly visible 2α structure with the ground state deformation $\beta_2 \simeq 1.20$. As seen in Fig. 1, inserting the antiproton results in a much less elongated nucleus ($\beta_2 \simeq 0.23$) without noticeable cluster structure. The binding energy increases from 53 MeV to about 700 MeV. Similar, but weaker effects have been predicted [4] for the case of the K^- bound state in the ^8Be nucleus.

The crucial question concerning possible observation of the SBNs is their life time. The only decay channel for such states is the annihilation on surrounding nucleons. The energy available for annihilation of bound antinucleon equals $Q = 2m_N - B_N - B_{\bar{N}}$, where B_N and $B_{\bar{N}}$ are the corresponding binding energies. In our case this energy at

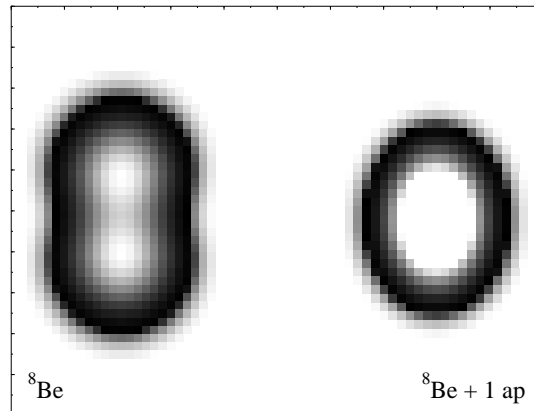


Figure 1: Contour plot of nucleon densities for ^8Be without (left) and with (right) antiproton calculated with the parametrization NL3.

least by factor of two smaller as compared to annihilation in vacuum. Taking into account the phase space reduction factors we estimate the SBN life times at the level of 15–20 fm/c which makes their observation feasible. Even longer life times may take place for SBNs containing antihyperons.

We believe that such exotic nuclear states can be produced in $A(\bar{p}, N)A'$ reactions by using antiproton beams of multi-GeV energy, e.g. at the future GSI facility. A rough estimate of the SBN formation probability in a central $\bar{p}A$ collision gives the values $10^{-4} - 10^{-3}$. Several signatures of SBN can be used for their experimental observation. First, annihilation of bound antibaryon can proceed via emission of a single pion or kaon with energy around 1 GeV (such annihilation channels are forbidden in vacuum). Another strong signal may come from radial motion of target nucleons at the initial stage of the SBN formation. This will excite a monopole-like oscillations around the compressed SBN state. One can also measure the collective flow of fragments escaping the expanding nucleus after annihilation of antibaryon.

References

- [1] Y. Sugahara and H. Toki, Nucl. Phys. **A579** (1994) 557.
- [2] M. Bender, K. Rutz, P.-G. Reinhard, J.A. Maruhn, and W. Greiner, Phys. Rev. **C60** (1999) 34304.
- [3] G. Mao, H. Stöcker, and W. Greiner, Int. J. Mod. Phys. **E8** (1999) 389.
- [4] Y. Akaishi and T. Yamazaki, Phys. Rev. **C65** (2002) 044005.