Exotic dibaryons with a heavy antiquark

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KEK theory center workshop on J-PARC hadron physics in 2014, Ibaraki Quantum Beam Research Center, Ibaraki, 2/10 - 12, 2014

1. Introduction

- The anticharmed (bottom) dibaryons, $\bar{D}NN$ (BNN), are genuinely exotic states. Their bound states are stable against a strong decay.
- They provide us with information about the meson-nucleons interactions, impurity effects caused by the heavy meson, etc.
- The interaction between a heavy meson and a nucleon is **attractive due to the one pion exchange potential (OPEP)** which appears through the $\bar{D}N - \bar{D}^*N$ mixing.
  Therefore, we expect existence of $\bar{D}NN(BNN)$ bound states.

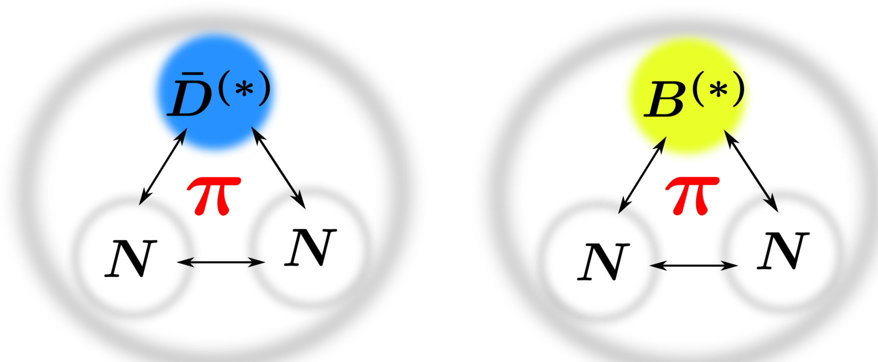

Figure 1: Exotic dibaryons, $\bar{D}NN$ and BNN.

2. Heavy Quark Symmetry and OPEP

- Heavy quark spin symmetry[1] manifests **the degeneracy** of heavy pseudoscalar meson $\boldsymbol{P = \bar{D}, B}$ and vector meson $\boldsymbol{P^* = \bar{D}^*, B^*}$.
  [1] N. Isgur and M. B. Wise, PLB**232**(1989)113, PRL**66**(1991)1130
- This is caused by suppression of a spin-dependent force in the heavy quark limit $(m_Q \to \infty)$.
  Indeed, the mass splitting between P and P^* is small,

$$m_{B^*} - m_B \sim 45 \text{ MeV}, \quad m_{D^*} - m_D \sim 140 \text{ MeV}$$

- The OPEP appears through the $PP^*\pi$ and $P^*P^*\pi$ vertices. ($PP\pi$ is forbidden due to the parity conservation.)
- **Tensor force** of the OPEP mixing the PN and P^*N channels generates a strong attraction.
- The mass degeneracy makes the $PN - P^*N$ mixing more effective. $\to$ The OPEP plays an important role between a heavy meson and a nucleon.

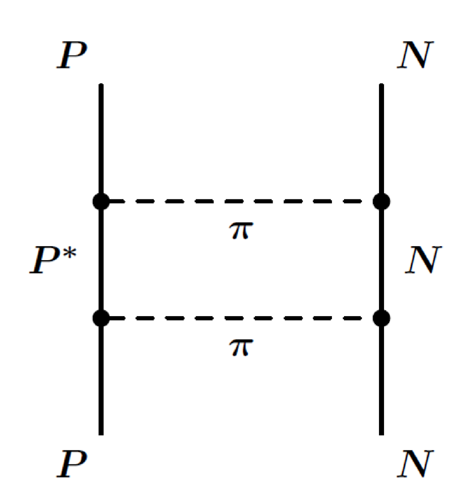

Figure 2: The π exchange potential mixing $PN - P^*N$.

- π exchange potential of $V_{P^{(*)}N}$; (S. Yasui and K. Sudoh, PRD**80**(2009)034008)

$$V_{PN-P^*N}(r) = -\frac{g_\pi g_{\pi NN}}{\sqrt{2}m_N f_\pi}\frac{1}{3}[\vec{\varepsilon}^{\dagger}\cdot\vec{\sigma}\,\underbrace{C(r;m_\pi)}_{\text{Central force}} + S_\varepsilon \underbrace{T(r;m_\pi)}_{\text{Tensor force}}]\vec{\tau}_P\cdot\vec{\tau}_N,$$

$$V_{P^*N-P^*N}(r) = \frac{g_\pi g_{\pi NN}}{\sqrt{2}m_N f_\pi}\frac{1}{3}[\vec{T}\cdot\vec{\sigma}C(r;m_\pi) + S_T T(r;m_\pi)]\vec{\tau}_P\cdot\vec{\tau}_N,$$

$(g_\pi = 0.59,\ g^2_{\pi NN}/4\pi = 13.6,\ f_\pi = 132$ MeV)

- NN interaction: AV8′ potential (B. S. Pudliner, *et al.*, PRC**56**(1997)1720)

$$V_{NN}(r) = \sum_{p=1}^{8} v'_p(r)\mathcal{O}^p$$

$$\mathcal{O}^{p=1,\cdots,8} = 1,\ (\vec{\sigma}_1\cdot\vec{\sigma}_2),\ (\vec{\tau}_1\cdot\vec{\tau}_2),\ (\vec{\sigma}_1\cdot\vec{\sigma}_2)(\vec{\tau}_1\cdot\vec{\tau}_2), S_{12},\ S_{12}(\vec{\tau}_1\cdot\vec{\tau}_2),\ \vec{L}\cdot\vec{S},\ \vec{L}\cdot\vec{S}(\vec{\tau}_1\cdot\vec{\tau}_2)$$

3. Numerical Results

- Bound states and resonances are studied.
- By diagonalizing the Hamiltonian $H = T + V_{P^{(*)}N} + V_{NN}$, the eigenenergies are obtained.
- Wave function is expressed by the Gaussian expansion method[2].
- For resonances, the complex scaling method[3] is employed.
  [2] E. Hiyama, *et al.*, Prog. Part. Nucl. Phys. **51**(2003)223 [3] S. Aoyama, *et al.*, PTP**116**(2006)1
- As a result, **Bound states** with $J^P = 0^-$ and **Resonances** with $J^P = 1^-$ are found for $\bar{D}NN$ and BNN.

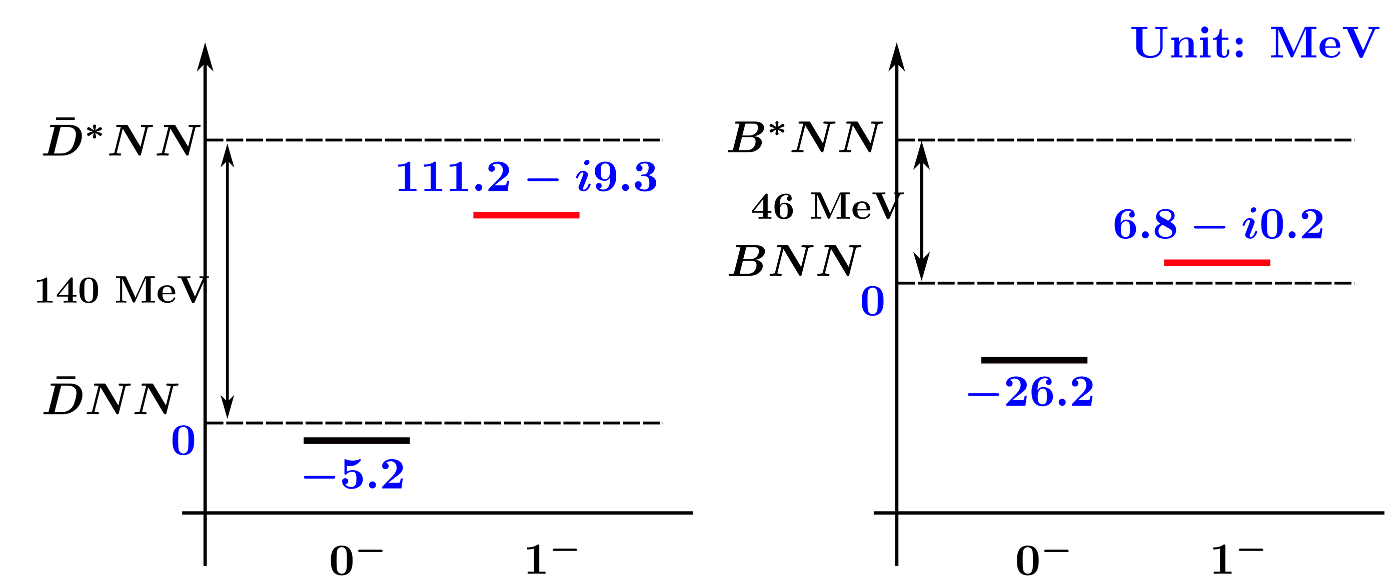

Figure 3: Energy levels for $\bar{D}NN$ and BNN with total isospin $I = 1/2$.
YY, S. Yasui, and A. Hosaka, arXiv:1309.4324 [nucl-th]

4. Energy expectation values

- For the bound states, the energy expectation values of the potentials are estimated.

$\bar{D}^{(*)}NN$	$\langle V_{\bar{D}N-\bar{D}^*N}\rangle$	$\langle V_{\bar{D}^*N-\bar{D}^*N}\rangle$	$\langle V_{NN}\rangle$
Central	-2.3	-0.1	-9.5
Tensor	-47.1	0.7	-0.2
LS	—	—	-0.03

YY, S. Yasui, and A. Hosaka, arXiv:1309.4324 [nucl-th]

- The tensor force of the $V_{\bar{D}N-\bar{D}^*N}$ generates the strong attraction.
  $\Rightarrow$ This force is the driving force to form the bound state.
- For V_NN, the central force is stronger than the tensor force.
  $\Rightarrow$ $NN(0^+)$ subsystem dominates in the bound states, while $NN(1^+)$ (=Deuteron) subsystem is minor.
- Similar behavior is found in the BNN bound states.

6. Summary

- Exotic dibaryons formed by $\bar{D}NN$ and BNN are investigated.
- Considering the Heavy Quark Symmetry, we introduce π exchange potential between a heavy meson and a nucleon.
  As for a realistic NN potential, the AV8′ potential is employed.
- We found a bound state with $J^P = 0^-$ and a resonance with $J^P = 1^-$ both in $\bar{D}NN$ and BNN.
- The tensor force of OPEP between the heavy meson and the nucleon plays a crucial role to produce the strong attraction.

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