Long range interaction of antiprotonic helium with helium

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Synopsis We intent to report our study of dispersion coefficients as well as long range interaction between helium ground state and antiprotonic helium $\bar{p}^3$He$^+$ and $\bar{p}^4$He$^+$ states, $(n, \ell = n{-}1)$. Sstatic polarizabilities of antiprotonic helium metal states are present as well.

The antiprotonic helium $\bar{p}$He$^+$ is an important three-body Coulomb system that may reveal the problem of CPT symmetry in particle physics. Its precision spectroscopy can be used to determine the antiproton-to-electron mass ratio by comparison of experimental [1, 2] and theoretical [3] frequencies for some selected transitions in $\bar{p}^3$He$^+$ and $\bar{p}^4$He$^+$. In the recent plans of the ASACUSA collaboration at CERN [4, 5] it is announced that they want to slow down the pulsed antiproton beam up to 150 eV and to cool down the experimental helium target to $T \leq 1.5$ K. For precision spectroscopy beyond 1 ppb level the long range interaction between antiprotonic helium and ground state helium atoms is of great importance for proper evaluation of collisional effects on the experimentally observed spectral lines. Also the Stark effect needs to be considered for future precision spectroscopy of the antiprotonic helium.

In our contribution we intend to address these problems and to report accurate numerical results for metastable states with circular $\bar{p}$ orbitals, $(n, \ell = n-1)$, in $\bar{p}^3$He$^+$ and $\bar{p}^4$He$^+$ atoms. Here ℓ is the orbital angular momentum quantum number, and n is the principal quantum number of the antiprotonic orbital. The three-body eigenvalue problem is variationally solved by the Hylleraas basis set. The wave function of a state of total angular momentum L and total spatial parity $\lambda = (-1)^L$ may be expanded as [3, 6]

$$\Psi^{L\lambda}_M(\mathbf{R}, \mathbf{r}) = \sum_{l+l_e=L} R^l r^{l_e} \{Y_l \otimes Y_{l_e}\}_{LM} G^{L\lambda}_{ll_e}(R, r, \theta)\,,$$

where $\mathbf{R}$ and $\mathbf{r}$ are position vectors of $\bar{p}$ and of an electron relative to the helium nucleus. This method is very effective for calculating nonrelativistic energy of three-body coulomb system, which can achieve one part in 10^{13} precision for $\bar{p}$He$^+$ [3, 6].

Long range interaction $U(R_{ab})$ between two particles, a and b, at large separation R_{ab} can be determined with dispersion coefficients and multi-pole static polarizabilities [7, 8]. The dipole polarization of $\bar{p}$He$^+$ is obtained with accuracy of 5 digits with about 1500 basis, while quadruple polarization about 4 digits with about 2000 basis. For the dispersion coefficients C_6, its numerical value has 6 reliable digits.

Table 1. Numerical values of static polarizabilites α_1, α_2 and dispersion coefficients for $\bar{p}^4$He$^+$ in a.u.,[n]denotes 10^n.

$(\nu = 0, L)$	α_1	α_2	$C_6(M_b = 0)$
$L = 34$	1.14519	0.3381[7]	1.37840
$L = 35$	0.924050	0.1185[6]	1.31765
$L = 36$	0.694032	0.2137[5]	1.26939
$L = 37$	0.449771	6355	1.23697

Some results are listed in Table **1**. Thus, the long range interaction between helium and $\bar{p}$He$^+$ can be obtained. Moreover, the collisional shift and broadening of transition lines of antiprotonic helium at low temperature [5, 9] can be estimated.

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