Examination of quasi-bound states of He $\overline{\mathrm{p}}$ and the possible existence of a bound state

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There is continuing interest in antihydrogen ($\overline{\mathrm{H}}$) following the successful preparation of $\overline{\mathrm{H}}$ by the ATHENA and ATRAP projects. See, for example, [1], [2]. He $\overline{\mathrm{p}}$ + e^+ is a rearrangement channel of He + $\overline{\mathrm{H}}$. He $\overline{\mathrm{p}}$ has been studied within the Born-Oppenheimer approximation. Using an approach similar to that of Jonsell *et al.* in their calculations for H$\overline{\mathrm{H}}$ [3], the electronic energy curve of He $\overline{\mathrm{p}}$ has been calculated using the variational method with basis sets containing up to 768 Hylleraas-type basis functions.

The energies and nuclear wave functions for 50 s states have been obtained from our potential by solving the nuclear wave equation numerically using the Cooley-Numerov algorithm. We intend to use the present calculations, along with entrance channel wave functions derived by a variational calculation by Armour *et al.* [4], to calculate cross sections for the He + $\overline{\mathrm{H}}$ $\rightarrow$ He $\overline{\mathrm{p}}$ + e^+ rearrangement.

For the state with the lowest energy we calculate an energy, within the BO approximation, which is below the threshold for binding. However the competing effects of the BO approximation and the variational method will lower or raise slightly the calculated energy, respectively, when compared to the true energy value. If no bound state exists, He $\overline{\mathrm{p}}$ has a quasi-bound state very close to the threshold for binding. The remaining states are all above the lowest continuum threshold for He $\overline{\mathrm{p}}$ and are thus quasi-bound states.

For the low energy states of He $\overline{\mathrm{p}}$ we find that the nuclei are so close together that is very like H^-.

References

[1] Amoretti M *et al.* 2004 *Phys. Lett. B* **578** 23

[2] Story C H *et al.* 2004 *Phys. Rev. Lett.* **93** 263401

[3] Jonsell *et al.* 2001 *Phys. Rev. A* **64** 052712

[4] Armour E A G *et al.* 2004 *Nucl. Instrum. Methods B* **221** 1