IONIZATION OF HELIUM BY ANTIPROTONS

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We report the single ionization cross section for $\bar{p}$ - He collisions using a single centre coupled state approximation [1] where the electron wave function is expanded in terms of a B-spline basis. The relevance of B-splines in the present situation is their ability to represent the continuum (ionizing) channels accurately.

Theory

We assume that the $\bar{p}$ moves along a straight line trajectory, $\mathbf{R} = \mathbf{b} + \mathbf{v}$t, with $\mathbf{b}$ the impact parameter, $\mathbf{v}$ the impact velocity and t the time. We adopt an independent electron model of the atom. For each electron in He the Schrodinger equation is written, in atomic units, as

$$(H_{IP} + V_{int} - i\frac{\partial}{\partial t})\Psi(\mathbf{r}, t) = 0 \qquad (1)$$

where $\mathbf{r}$ is the position vector of the electron with respect to the atomic nucleus. The atomic Hamiltonian (H_{IP}) is given by

$$H_{IP} = -\frac{1}{2}\bigtriangledown^2 + V_{eff}(r)$$

and

$$V_{int} = \frac{1}{|\mathbf{r} - \mathbf{R}|}$$

is the time dependent interaction between the projectile and the target electron. The effective potential V_{eff}(r) is of the form

$$V_{eff}(r) = -\frac{q}{r} - \frac{exp(-\lambda r)}{r}(a + br)$$

where $a = (Z-q)$=1, with $Z = 2$ and $q = 1$ being the nuclear and asymptotic charges of the He$^+$ ion. The two arbitrary parameters b and λ are are taken to be b= 0.502 and $\lambda = 2.51$. This gives a 1s orbital binding energy -0.9031 au which is close to the ionization potential -0.904 au of the He atom.

The total wave function is expanded as

$$\Psi(\mathbf{r}, t) = \sum_{nlm} a_{nlm}(t)\phi_{nlm}(\mathbf{r})exp(-i\varepsilon_{nl}t), \qquad (2)$$

where $\phi_{nlm}(\mathbf{r})$ is given by

$$F_{nl}(r)[(-1)^m Y_{lm}(\mathbf{r}) + Y_{l-m}(\mathbf{r})]/\sqrt{2(1+\delta_{m,0})}.$$

The radial part of the wave function $\phi_{nlm}(\mathbf{r})$ is further expanded as

$$F_{nl}(r) = \sum_i c^l_{ni}\frac{B^k_i(r)}{r}$$

where the B^k_i(r) are k-th order B-spline functions.

Using (1) and (2) we obtain coupled equations for the expansion coefficients $a_{n'l'm'}(t)$,

$$i\frac{d}{dt}a_{n'l'm'}(t) = \sum_{nlm} exp[i(\varepsilon_{n'l'} - \varepsilon_{nl})t]V_{n'l'm',nlm}a_{nlm}(t)$$

where $V_{n'l'm',nlm} =< \phi_{n'l'm'}|V_{int}|\phi_{nlm} >$. These are solved with respect to the initial conditions: $a_{n'l'm'}(-\infty)$=$\delta_{n'l'm',1s}$. The sum of the probabilities $P_{nlm}(b) = |a_{nlm}(\infty)|^2$ over states ϕ_{nlm} with positive energies ϵ_{nl} gives the ionization probability for a particular impact parameter. The single ionization cross section of He in the so called independent particle model (IP) is then given by

$$\sigma = 2\pi\int_0^\infty 2P(b)(1 - P(b))bdb,$$

where

$$P(b) = \sum_{nlm,\epsilon_{nl}>0} P_{nlm}(b).$$

Results will be presented at the Conference.

References

[1] S. Sahoo, S. C. Mukherjee and H. R. J. Walters, J. Phys. B **37** 3227 (2004).