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Three-Body Coulomb Resonances in Hydrogenic Plasmas

TOLSTIKHIN Oleg I., TOLSTIKHINA Inga Yu.,[1,2] and NAMBA Chusei[2]
Russian Research Center "Kurchatov Institute", Kurchatov sq. 1, Moscow, 123182, Russia
[1]P. N. Lebedev Physical Institute, Leninsky Prospect 53, Moscow, 117924, Russia
[2]National Institute for Fusion Science, Toki 509-5292, Japan

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Abstract

Results of a systematic study of the lowest $^1S^e$ Feshbach resonance in symmetric three-body Coulomb systems are reported. We found that the resonance width oscillates as a function of the mass-ratio of the constituting particles and maybe even vanishes at certain values this parameter. These oscillations are interpreted as a result of the interference between two different paths of the resonance decay.

Keywords:
three-body Coulomb problem, resonance, H^-, H_2^+

With the increase of the density of particles the negative atomic ions H^- and the positive molecular ions H_2^+ become abundant in hydrogenic plasmas. Both systems play an important role in plasma diagnostics and their spectroscopic observations may provide a valuable information on plasma's characteristics [1]. However, while H^- is a well studied system the high precision theoretical and experimental study of H_2^+ is just in its beginning. In this work we initiate a systematic study of the lowest $^1S^e$ Feshbach resonance in symmetric three-body Coulomb systems ranging from H^- to H_2^+.

Resonances constitute a very important class of collision phenomena revealing a complicated interplay between attractive and repulsive forces acting in the collision system. Formal theory of resonances has long been completed by Breit and Wigner, Kapur and Pierles, Siegert, Feshbach, Fano, and many other authors. Among the existing methods of resonance calculations we mention the *R*-matrix theory, Kohn variational principle, complex rotation and stabilization methods. Each of these methods has its own merits, but they all suffer from the common drawback of being unable to treat narrow resonances in systems containing two or more heavy (in atomic scale) particles, such as H_2^+. This difficulty, as well as some conceptual problems of the theory of resonances, have been resolved in the new method based on Siegert PseudoStates (SPS) proposed recently in [2] and further developed in [3]. The SPS theory combines solid theoretical foundation with high computational efficiency and is able to provide reliable results even in the situations where other methods fail, as was demonstrated in [2].

In Fig. 1 we report our results of the SPS calculations of the resonance position E_{res} and width Γ defined by the resonance eigenvalue $E = E_{res} - i\Gamma/2$ as functions of the mass-ratio between the heavy and the light particles in the interval from 1 to 30. This interval complements our previous calculations for H^- [2], includes the $pp\mu$, $dd\mu$, and $tt\mu$ systems important for the muon catalyzed fusion project [4], and provides a one more step towards the attack on H_2^+. We found that the resonance width oscillates with the variation of the mass-ratio and maybe even vanishes at certain values of this parameter. Qualitative interpretation of these

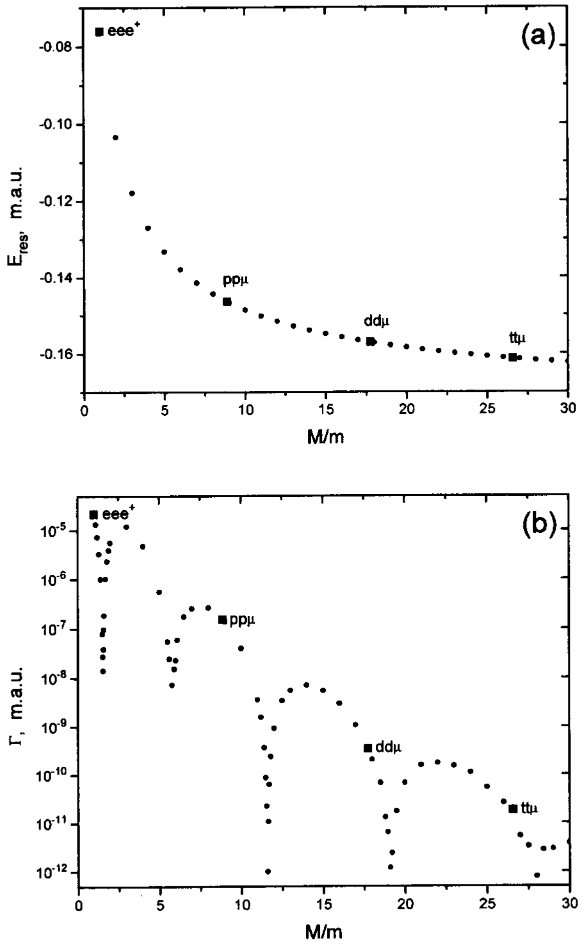

Fig. 1 The resonance position (a) and width (b) as functions of the mass-ratio between the heavy and the light particles. The realistic physical systems existing in this interval of M/m are indicated in the figure.

oscillations can be given within Fano-Feshbach formalism and modern semiclassical theory. It can be shown that the oscillations result from an interference between two paths of the decay of the resonance state. One of these paths leads directly from the region of localization of the resonance wave function to the fragmentation region while the other one first passes through the turning point on the lowest adiabatic potential. The very small value of the resonance width at certain values of the mass-ratio results from the distructive interference of these two paths. This indicates a very interesting possibility of existence of bound state embedded in the continuum of the three-body Coulomb problem.

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