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Collisional transitions between HFS states of antiprotonic 3He in the presence of microwave radiation

Recently, the first experimental results for laser-microwave-laser spectroscopy of the hyperfine structure of antiprotonic 3He were published [1]. Along with the
measurements of hyperfine splitting of the levels and relevant fundamental properties of antiproton, such experiments can provide an interesting information on collisional transitions and interaction of antiprotonic helium with a medium. In this paper we consider collisional effects on the HFS states transitions of antiprotonic 3He in the presence of microwave radiation. A theoretical description of these effects involves two parts: (i) calculations of the elementary collision characteristics (cross sections, transition rates, collisional shifts and broadening of spectral lines) vs. energy and an average of these values over thermal motion, and (ii) analysis of the time evolution of the HFS states density matrix. Similar problems were already considered for HFS transitions in antiprotonic 4He [2,3]. We use here the same approach for antiprotonic 3He with 8 HFS states instead of 4 for 4He. The parameter of the quadruple interaction strength was taken from the fitting [3] of the results to the experimental data for 4He [4].
Using the model interaction between antiprotonic and ordinary helium atoms, we solve quantum close-coupling equations in the subspace of eight HFS states of antiprotonic 3He. From the obtained S-matrix we calculate elastic and inelastic cross sections, transition rates, collisional shift and broadening of M1-spectral lines depending on collision energy. Averaging over thermal motion gives a temperature dependence of these values. The second part of the problem was considered starting from the quantum master equation [5] for the density matrix of the eight HFS states. The relaxation matrix in the master equation is expressed in terms of the calculated elementary collision characteristics. Time dependence of the density matrix was obtained by a numerical solution of the master equation within "secular" and "rotating wave" approximations.
From the calculations we conclude that partial rates of the single spin-flip transition between HFS states in antiprotonic 3He are about 10^6 1/s at the density 3*10^{20} 1/cm^3 and the temperature 6 K, whereas effective relaxation rate with consideration for the kinetics is greater, at least, by factor 2. Collisional shifts of the M1 spectral lines at the same conditions are about 3 kGz, i.e., far less than achieved accuracy of measurements [1] as well as of the theoretical 3-body calculations [6]. Collisional broadening of the lines is calculated to be less than 0.5 MGz. The total width at T=350 ns is about 2.4 MGz allowing for non-additive collisional and Fourier broadenings. Maximum value of the value (peak/total -1) in the 3He target is less by half as compare with 4He at the same delay time T between the two laser pulses.

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