The Stark effect on the hfs of Cs atoms and blackbody radiation shift

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Cs atom is used in a number of important applications including atomic clocks, laser cooling, parity violation experiments, the search for a permanent electron dipole moment, atom interferomertry, etc. Precise measurements of Stark effect provide information about susceptibilities of atomic states that are important for describing of atomic properties including van der Waals constants and dielectric constants, anticrossings of atomic levels occuring in the Stark splitting of multiplet at an electric field.

The Stark effect on the hyperfine-structure (hfs) occurs as a result of disturbance of atomic levels under the influence of the interaction between electron and nuclear magnetic dipole moment as well as the interaction with electric field. The interaction between Cs atoms and the electric fields of blackbody radiation (BR) produces the Stark effect on the hfs of sublevels for the ground state [1], which leads to a shift of the frequency in the frequency standards employing laser-cooling techniques for Cs atoms [2, 3]. It is important to note, that BR shift is one of the dominant uncertainty term, which could limit the accuracy of this kind of the frequency standards.

The main goal of this paper is to analyze the higher-order Stark effect on hfs -components of Cs atoms both in the ground and excited states as well as the temperature-dependent shift of $6S_{1/2}$ hfs splitting due to the BR on the $6S_{1/2}(f=3, M_f=0)-(f=4, M_f=0)$ clock transition. The contents of the present paper can roughly be divided into two main parts.

The first part contains the general theory of higher-order Stark effect including hyperfine structure effects. We modify and extend the theory in several ways. We consider the problem of the hfs in the presence of a uniform electric field using rather general angular momentum arguments to show how the different hfs-interactions contribute (magnetic dipole contact interaction, magnetic dipole orbital interaction, magnetic spin-dipolar interaction and electric quadrupole interaction). We introduce few separate differential susceptibilities to describe of the electric field splitting. It is shown, in particular, that the BR shift appears in the third- and fifth orders of perturbation theory, where the electric-field interaction is taken 2 times (polarizabilities) and 4 times (hyperpolarizabilities) and the hyperfine interaction is taken only once. The general expressions for the polarizabilities and hyperpolarizabilities have different representations depending on the total angular momentum and can be written in terms of the scalar and tensor parts. Our arguments up to this point are equally valid for Cs atoms in the ground and excited states.

We employ two alternative calculating approaches based on the sums of oscillator strengths and on the Green' function method in the framework of the Fues' model potential approximation. The effectiveness of the method of Green' functions is largely determined by the existence of appropriate representation of these functions. In this paper we have taken the analytical representation for the Green' function [4].

As a result, in the proposed computational method, on the one hand, the requirement for integration over the continuum spectrum is eliminated and, on the other, reliable control of accuracy is ensured, in contrast to methods involving the integration of inhomogeneous differential equations.

The results are compared with experiments [2, 3] and with calculations by other authors [1, 5]. The comprehensive analysis of uncertainty for the BR shift, including both experimental and theoretical results, is also presented here.

In the second part, we estimate the dc hyperfine Stark shifts on $6P_{3/2}$ excited state in Cs both theoretically and experimentally using specially designed cesium cell and found that this effect is large enough to be observable with a resolution on the level 10^{-10} [6].

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