Hyperfine Splitting of Hydrogenlike Thallium

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The investigation of hydrogenlike highly-charged ions is of interest for nuclear as well as for atomic physics. Measuring the ground-state hyperfine structure (HFS) splittings of these ions is a sensitive method to explore QED in extremely strong electric and magnetic fields and nuclear contributions to the electron energy. However, for a theoretical interpretation of the results it is necessary to separate the different contributions. Nuclear models have to provide charge and magnetization distributions of nuclei, which lead to the Breit-Rabi and the Bohr-Weisskopf effect, respectively, and corrections to the electron energy have to be calculated with QED. Interest was first focussed on the isotopes $^{207}Pb^{81+}$ and $^{205}Bi^{82+}$, where the theoretical description is simplified since they differ only by one nucleon from doubly-magic ^{208}Pb. The hyperfine structure of these isotopes was measured at GSI with laser spectroscopy at the ESR [1]. More recently, the hyperfine structure of $^{165}Ho^{66+}$, $^{185}Re^{74+}$, and $^{187}Re^{74+}$ was obtained by passive photon-emission spectroscopy in a high-energy electron-beam ion trap (SuperEBIT) at Livermore [2]. Similar experiments are presently under preparation to determine the HFS of thallium isotopes [3].

Previously, we applied the Dynamic Correlation Model (DCM) [4] to the hydrogenlike ions $^{207}Pb^{81+}$, $^{205}Bi^{82+}$, $^{165}Ho^{66+}$, and $^{185,187}Re^{74+}$ to derive the nuclear part in the HFS and combined the results with QED corrections [5]. The calculated hyperfine splittings are summarized in Table 1 and compared with other theoretical expectations [6, 7, 8] and experimental data. It turned out that the pure DCM results agree well with the experimental data, while adding the QED corrections led to a systematic deviation between theory and experiment. This is in contrast to the good description of nuclear properties by the dynamic correlation model and has motivated the application of the DCM to predict the HFS of the hydrogenlike thallium isotopes $^{203,205,207}Tl^{80+}$. The results are also included in Table 1. Besides, these calculations may guide future experiments at the GSI storage ring since an accurate *a priori* knowledge of the HFS transition frequency is required to avoid prohibitive large scan ranges.

In the DCM three terms contribute to the HFS: The first term is due to the single-hole magnetization, the second term was introduced in perturbative theory and describes spin-flip excitations [9], and the third term allows for collective correlation effects in the nucleus [5], it corresponds to higher-order perturbation diagrams. Taking these three terms into account the calculations accurately reproduce the experimental HFS. The systematic discrepancy to experimental data, which is observed after adding the QED corrections, might be the result of a double counting effect: The DCM calculations include "de facto" virtual mesons, which can decay into e^+e^- pairs, and these might be considered in radiative corrections as well. Another possibility is that the nuclear correlations, which are not taken into account in QED calculations, have a distinct influence on the radiative corrections. Hence, the central question is how to compare the DCM terms and the radiative corrections of Refs. [10, 11]. The importance of this problem is evident: In the extreme single-particle model, QED and nuclear-magnetization corrections for high-Z atoms are of the same order of magnitude. Thus, the feasibility of testing the QED corrections depends strongly on the accuracy of the model used to evaluate the nuclear magnetization.

Table 1: Wavelengths of transitions between the ground state HFS components in hydrogenlike ions as calculated in the DCM and after combination with QED corrections taken from [11]. For comparison other theoretical and experimental data is given. All values in nm.

Ion	Theory			Exp.
	DCM	+QED	Other	
$^{165}Ho^{66+}$	572.71	575.44	572.5 [7]	572.79(15)[2]
			563.9 [8]	
$^{185}Re^{74+}$	455.96	458.36	451.0 [7]	456.05(30)[2]
			448.6 [8]	
$^{187}Re^{74+}$	451.69	454.06	-	451.69(30)[2]
$^{207}Pb^{81+}$	1019.1	1024.76	1020.5 [7]	1019.7(2) [1]
			1017.0 [8]	
$^{209}Bi^{82+}$	243.91	245.26	243.0 [7]	243.87(2) [1]
			241.2 [8]	
$^{203}Tl^{80+}$	385.89	388.01	383.98[6]	
			384.0 [7]	
			382.2 [8]	
$^{205}Tl^{80+}$	382.79	384.89	380.22[6]	-
			380.2 [7]	
			378.6 [8]	
$^{207}Tl^{80+}$	377.68	379.74	-	-

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