Contributions to helium fine structure at order $m\,\alpha^7$

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Helium fine structure, the splitting of helium 2^3P_J-levels, is presently the subject of intensive theoretical and experimental studies. While several experimental groups, particularly Inguscio *et al.* [1], Hessels *et al.* [2], and Shiner *et. al.* have already reached the few kHz level of precision, the theoretical predictions are far less accurate, primarily due to the unknown value of the $m\,\alpha^7$ correction. It is our goal to test quantum electrodynamic computational methods for the bound state problem, and in addition to obtain a precise value of the fine structure constant α from the measured values of helium fine structure.

The theoretical description of three body systems in quantum electrodynamics is a quite complicated task. All methods use a perturbative expansion in α. Since the leading contribution to helium fine structure is a relativistic effect, one has to develop a systematic treatment of relativistic, or more generally QED, effects for this three body system. In the leading orders of $m\,\alpha^4$ and $m\,\alpha^5$ the fine structure can be calculated using only the Breit interaction. However, the next order of $m\,\alpha^6$ requires a complete QED treatment, originally carried out using the Bethe-Salpeter equation. Douglas and Kroll in [4] were able to rearrange this equation into a Shrödinger like form, with extra operators acting on the nonrelativistic wave functions. However, these operators are highly singular, and are finite only for triplet P states. New methods, based on the technique of effective Hamiltonians [5], are required for the treatment of S-states [6].

New methods are also required for the challenging project of the calculation of the $m\,\alpha^7$ contribution to helium fine structure. The logarithmic contribution in this order has been treated in [7]. The regulators introduced in [6] to handle divergent terms for S-states in order $m\alpha^6$ lead to an explosion in the already large number of complicated operators for fine structure in order $m\alpha^7$. Therefore, as a first step, we propose to calculate the numerically most significant part, which come almost solely from soft photons. This part can be understood as a correction to Bethe-logarithm terms due to spin-orbit and spin-spin interactions.

We will present numerical values for this numerically most significant part together with improved theoretical predictions for the helium fine structure.

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