Completion of QED-calculations for hydrogenlike uranium

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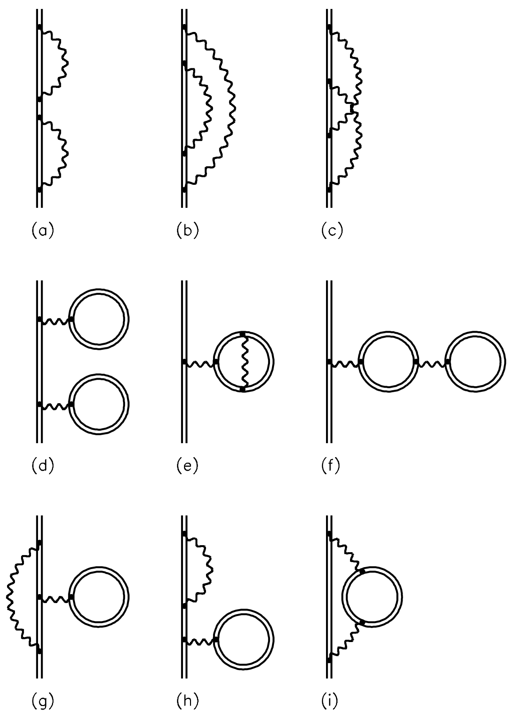
To test QED in strong external fields has initiated intensive theoretical and experimental activities. Measurements of the Lamb shift in highly charged ions at utmost precision are considered as ideal scenario for this purpose [1]. Accordingly, to provide predictions for the ground-state energy in H-like uranium with relative accuracy of about 10^{-6} – this ultimate limit is set by nuclear polarization effects and uncertainties in the parameters – necessitates the evaluation of all QED corrections of order α^2 but to all orders $Z\alpha$ in the interaction with the Coulomb field of the nucleus.



The unknown contributions of the two-photon self energy SESE (a), SESE (b) and SESE (c), which are most difficult to calculate, were considered to represent the major theoretical uncertainty. Here we report on the solution of this challenging problem and present exact results for the energy shift of the $1s$-ground state in H-like uranium due to *all* SESE diagrams. A first estimate for hydrogenlike uranium in the so called *sign-approximation* has been presented in [2]. For the first time a rigorous calculation of all second-order self-energy diagrams for the $1s_{1/2}$-state in H-like uranium is now available [3]. The results are compiled in the table together with all relevant QED-corrections of order α and α^2 and nuclear effects.

The diagram SESE (a) consists of an irreducible (*irred.*) and a reducible (*red.*) part. The contribution SESE (a) (irred.) can be renormalized and evaluated separately. It has been calculated first in Ref. [4] for high nuclear charge numbers Z and recently for arbitrary values of Z in Refs. [5, 6]. Although the results obtained are in fair agreement for high Z a discrepancy between those in Refs. [5] and [6] has been observed in the case of low and intermediate Z values. For uranium an incomplete calculation of all SESE contributions has been presented in Ref. [7]. For our complete evaluation of SESE we adopt the renormalization scheme, which is based on (double) partial wave expansions. To evaluate summations over the Dirac spectrum we utilize the B-Spline method.

Dirac energy	-132279.66	eV
Finite nuclear size	198.82 ± 0.10	eV
QED-corrections of order α:		
Self energy	355.05	eV
Vacuum polarization	-88.60	eV
QED-corrections of order α^2:		
SESE (a) (irred.)	-0.97	eV
SESE (a) (red.) (b) (c)	1.21 ± 0.12	eV
VPVP (d)	-0.22	eV
VPVP (e) (Uehling)	-0.60 ± 0.01	eV
VPVP (f)	-0.15	eV
SEVP (g),(h)	1.12	eV
S(VP)E (i) (Uehling)	0.13	eV
Relativistic recoil	0.16	eV
Nuclear polarization	-0.20 ± 0.10	eV
Lamb shift (theory)	465.7 ± 0.33	eV
Lamb shift (experiment)	470.0 ± 16	eV

With the present result at hand the most serious QED uncertainty in present Lamb-shift predictions has been removed. Nevertheless, it would be desirable to perform a complete calculation for the lead system as well. This system seems more favorable for precision tests of QED in strong fields since nuclear uncertainties are expected to be about one order of magnitude smaller.

References

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