The g-Factor of the Bound Electron in Hydrogen-like Ions: a High-Accuracy Test of Bound-State QED

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Introduction

The experimental determination of the magnetic moment (g-factor) of the bound electron in hydrogen-like ions is an important test of the theory of Quantum Electrodynamics in strong atomic Coulomb fields [1]. In our experiment a single hydrogen-like ion ($^{12}C^{5+}$) is stored in the magnetic field of a Penning trap. The g-factor is measured by inducing spin-flip transitions with a microwave field at the Larmor precession frequency of the bound electron. These spin-flip transitions are observed via the continuous Stern-Gerlach effect as quantum jumps of the hydrogen-like ion between the two possible spin orientations (*up* and *down*) [2]. This technique was first used by Dehmelt and coworkers in their $g-2$ experiment on a free electron in a Penning trap [3]. The magnetic field is calibrated by measuring the cyclotron frequency of the stored ion. This "quantum-jump method" is applicable to any hydrogen-like ion.

g-Factor Measurement

In our first g-factor measurement [2] we reached an experimental accuracy of 10^{-6}. This accuracy was high enough to verify the relativistic contribution to the g-factor of the bound electron in hydrogen-like carbon ($^{12}C^{5+}$). Recently, we improved our measurement accuracy by a factor of 1000 with an optimized measurement technique where the spin-flip transitions are induced and detected at two different positions in the Penning trap. With the improved accuracy of 10^{-9} it is now possible, even for light hydrogen-like ions, to test the bound-state QED contributions to the g-factor of the electron.

The result of our new measurement of the g-factor of the bound electron in hydrogen-like carbon (C^{5+}) is

$$g^{exp}(C^{5+}) = 2.001\,041\,596\,(1)\,(1)\,(4)\,. \tag{1}$$

The first error is the statistical uncertainty, the second error arises from possible systematic shifts and the third one denotes the uncertainty in the knowledge of the atomic mass of the electron. Details of the systematic measurement uncertainties are discussed by Häffner et al. in a poster session during this conference. This experimental result is a sensitive test of bound-state Quantum Electrodynamics and is in excellent agreement with the most recent theoretical calculation [4]

$$g^{theo}(C^{5+}) = 2.001\,041\,591\,(5)\,. \tag{2}$$

The calculation includes all Feynman diagrams on the one-loop level giving a contribution of $844 \cdot 10^{-9}$ to the g-factor of the bound electron in hydrogen-like carbon (C^{5+}). The theoretical uncertainty of $5 \cdot 10^{-9}$ is mainly due to uncalculated Feynman diagrams on the two-loop level.

Atomic Mass of the Electron

The electron mass in atomic units is an important input parameter for our determination of the g-factor of the bound electron in hydrogen-like carbon (C^{5+}). Van Dyck and coworkers measured the atomic mass of the electron with an uncertainty of 2 ppb comparing the cyclotron frequencies of the electron and of the carbon ion in a Penning trap mass spectrometer [5]. Therefore, presently the knowledge of the electron mass is a main limitation to the theoretical interpretation of our g-factor measurement.

Alternatively, we can deduce the atomic mass of the electron from our precision measurement of the g-factor of the bound electron in hydrogen-like carbon (C^{5+}) using the theoretical value for the g-factor as calculated recently by T. Beier. The fractional accuracy of our value for the atomic mass of the electron is 2 ppb. Our value for the electron mass is in good agreement with the value of Van Dyck et al.

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