Bound Electron g-Factor in Hydrogen-Like Bismuth

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The transition between the hyperfine levels of the 1s ground state of heavy hydrogen-like ions can be excited by laser radiation [1][2]. In addition to transition energy measurements, the accurate determination of the transition probability in these systems is a way to achieve experimental values of the bound electron g-factors. These are sensitive probes for the test of electromagnetic interaction in extremely strong electric and magnetic fields.

The decay probability of an excited 1s hyperfine structure level in terms of the g-factor is given by [3]

$$w \propto E^3_{F\to F'} \cdot \frac{I}{2I+1}\left(g_e - \frac{m_e}{m_p} g_n\right)^2 \qquad (1)$$

($E_{F\to F'}$=transition energy, I=nuclear spin, g_e=bound electron g-factor, g_n=nuclear g-factor).

First measurements of g_e have been done on rather light systems (H, D, He^+ and C^{5+}), the latter in a Penning trap by inducing spinflips with a microwave field [4]. Lifetime measurements of the excited hyperfine state in $^{207}Pb^{81+}$[2] and $^{209}Bi^{82+}$[1] were performed by laser spectroscopy in the ESR but suffer from a lack in accuracy.

We now did a remeasurement of the hfs splitting and lifetime in $^{209}Bi^{82+}$. The ions, revolving at an energy of 300 MeV/u in the ESR, were excited in the straight cooler section by a counterpropagating laser beam from a pulsed frequency-doubled Nd:YAG laser. The pulses were 5 ns long at a repetion rate of 50 Hz. The ions passed by a solar blind photomultiplier that was installed behind the gas jet. The photomultiplier signal (Fig.1) was recorded by two independent methods: with a multiscaler, and a multi-hit TDC. The results from both methods agree. Measurements were done at three different electron cooler currents and also with the gas jet alternately switched on or off. We found no significant difference between the individual results. This means that there is no additional deexcitation process from intrabeam or residual gas scattering, at least not at this level of accuracy. The results of the two bismuth and the lead beamtimes are listed in Tab.1, together with theoretical values and related g-factors. The remeasurement of the transition energy resulted in perfect agreement with the old value.

The accuracy of this experiment is sufficient to test the relativistic correction. In addition there is good agreement with the theoretical value including QED but some disagreement, if QED effects are not included in theory, which would lead to $g_{e,\text{no QED}} = 1.7281$ for $^{209}Bi^{82+}$.

The large deviation of the old experimental result from the recent measurement and the calculation can probably be attributed to the software gating used in 1994 in order to enhance the signal-to-noise ratio. Only a small region of the coasting ion beam is subject to an excitation of the hyperfine transition by the short laser pulse. This can be pictured as a brightly fluorescent bunch revolving in the ESR. In the measurement by Klaft et al., the photomultiplier signal was only recorded during a sequence of time gates that were synchronized to the bunch passing the detector part of the ring. Obviously, due to the finite velocity distribution, excited ions drift out of the bunch and out of the gate. This leads to a reduction of the detected fluorescence rates in the tail of the signal curve and thereby to a reduced lifetime.

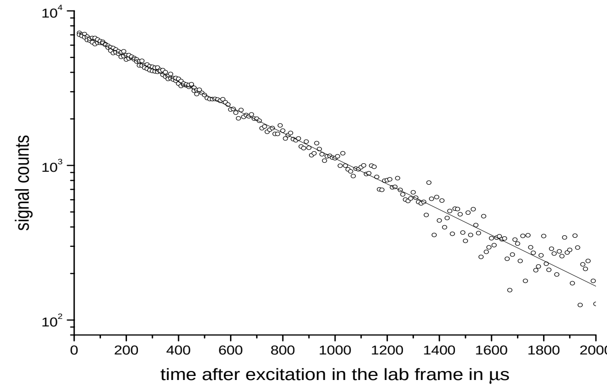

Figure 1: Fluorescence signal of $^{209}Bi^{82+}$ versus time after laser excitation in the laboratory frame. The fit results in a half-life of $\tau_{\text{lab}} = 524.9 \pm 2.0\,\mu$s.

Table 1: Theoretical [3] and experimental ($\dagger$:Ref.[1], $\ddagger$:Ref.[2], $\star$:this work) values for lifetimes and energies of the excited hyperfine level in $^{207}Pb^{81+}$ and $^{209}Bi^{82+}$ and the corresponding bound electron g-factors.

	$^{209}Bi^{82+}$		$^{207}Pb^{81+}$
lifetime, theo. [ms]	0.39901(19)		52.07(3)
lifetime, exp. [ms]	0.351(16)†	0.3975(15)*	49.5(6.5)‡
g-factor, theo.	1.7310		1.7383
g-factor, exp.	1.845(84)†	1.7341(35)*	1.78(12)‡
$E_{F\to F'}$ [eV]	5.0841(5)†	5.0843(4)*	1.2159(2)‡

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References

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