

Towards Precision Laser Spectroscopy of Forbidden Transitions in Highly-Charged Ions

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Introduction

The SPECTRAP experiment for the investigation of highly charged ions (HCI) at rest with methods of high-resolution laser spectroscopy is under development at GSI. The spectroscopic data can be used to test atomic structure and bound-state quantum electrodynamics (QED). Systematic measurements on several species of highly charged ions will be possible with up to three orders of magnitude better spectroscopic resolution than in former experiments [1]. Amongst others, related earlier measurements have been realized on bunches of $^{209}\text{Bi}^{82+}$ -ions in the experimental storage ring ESR. The value of the transition wavelength was determined to be 243.87(4) nm in the lab-frame [2, 3]. For improved precision in the measurement the ions will now be decelerated by the HITRAP-facility and cooled to liquid helium temperatures inside the SPECTRAP Penning trap.

Spectroscopic Apparatus

For spectroscopy on $^{209}\text{Bi}^{82+}$, the necessary laser system has to produce laser light with a power of several mW at 243.87 nm and a tuning range significantly larger than the standard deviation of 100 GHz of the previous measurement [2, 3]. In addition, the laser frequency should be stable to a precision and accuracy comparable to or below the expected Doppler-width of the transition of the ions inside the Penning trap which is expected to be approximately 30 MHz. For the generation of the light at the target wavelength we use a commercial frequency-quadrupled diode laser system. Through the successive frequency doubling we have access to laser fields at 244 nm, 488 nm and 976 nm. The light at 488 nm is used for frequency diagnostics on $^{130}\text{Te}_2$ vapour while the light at 976 nm is used for frequency stabilization to a cavity. Tuning of the output frequency with high precision is achieved via a tunable rf offset lock and coupling to the cavity.

For stabilization and frequency diagnostic, vapour of molecular tellurium $^{130}\text{Te}_2$ is used as spectroscopic reference. We recorded and analysed a set of resonances, delivering precise spectroscopic references on a continuous spectrum between 488.36 nm and 487.28 nm with an absolute accuracy of 3 MHz (one standard deviation). The data were compared to previous highly precise measurements of known tellurium features. The uncertainty of 3 MHz is caused by ambient pressure fluctuation and the limitations in the corresponding corrections. In a recent set of measurements, our absolute accuracy for some lines has been

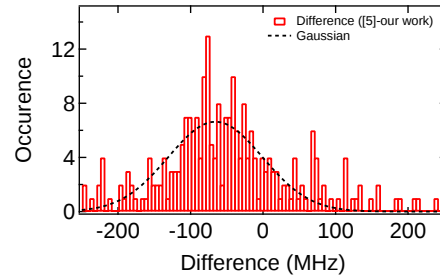


Figure 1: Histogram for the offset frequency between our Doppler-broadened measurements and the ones from [5].

improved to 0.9 MHz.

To constitute a map of $^{130}\text{Te}_2$ vapour, we switch between the zero crossings of the 976 nm cavity signal for stabilization. We took two sets of measurements which were then combined to one final average. For analysis, Gaussian and Lorentzian profiles were fitted to the averaged ensemble map. Those features which could be correlated to the ones listed in [5] were assigned accordingly. Additionally, we took five measurements scanning the previously calibrated features from the literature with the cavity placed inside a vacuum chamber. Taking several runs on known tellurium references gives us the possibility to quantify our precision by calibrating each run to two features with known absolute frequency. Comparing our Doppler broadened lines to the ones in [5], we could confirm previous results [6], that the atlas delivers smaller values by an average offset of 65.8 MHz (Fig. 1). As a result, we now have a high-precision map of tellurium lines in the range of 488.36 nm and 487.28 nm and a table with over 900 spectroscopic references.

References

- [1] M. Vogel, D.F.A. Winters, D.M. Segal, R.C. Thompson, *Rev. Sci. Ins.* **76**, 103102 (2005).
- [2] I. Kluft et al.: *Phys. Rev. Lett.* **73**, 2425 (1994).
- [3] S. Borneis et al.: *Hyp. Int.* **127**, 305 (2000).
- [4] S. Albrecht et al.: *Appl. Phys. B*, **107**, 1069 (2012).
- [5] J. Cariou, P. Luc: *Atlas du Spectre d’Absorption de la Molécule Tellure, 20300cm⁻¹ - 21195cm⁻¹* (Lab. Aime-Cotton CNRS, Paris, 1980).
- [6] J. D. Gillaspay and Craig J. Sansonetti: *J. Opt. Soc. Am B* **8**, 2414 (1991).