A new test of Time Dilation at ESR using fast $^7Li^+$-ions

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One of the fundamental principles in modern physics is Local Lorentz Invariance (LLI), which describes spacetime symmetry in the theories of the electromagnetic, the strong and the weak force as well as the local part of general relativity. Time dilation is one of the well known consequences of LLI and Special Relativity (SR), respectively.

In 2010 we have performed an experiment to probe time dilation by simultaneous measurements of forward and backward Doppler shifts of an electric dipole transition of fast moving ions. In the presented measurements, $^7Li^+$ ions are stored in the experimental storage ring (ESR) with a velocity of 33.8 % of the speed of light. Those ions have a strong dipole transition (2s → 2p) which has an excitation wavelength of $\lambda_0 = 548.5$ nm in the ions' rest frame. The transition is simultaneously addressed by two laser beams overlapped parallel (p) and anti parallel (a) with the ion beam. Due to the relativistic time dilation, the frequencies of the exciting lasers are shifted according to the Doppler formula to $\nu_{a,p} = \nu_0 \cdot \gamma \cdot (1 \pm \beta)$, where $\gamma = (1 - \beta^2)^{-1/2}$ is the Lorentz factor and $\beta = v/c$ is the velocity of the ions in terms of the speed of light. Multiplication of the Doppler shift formulas shows that SR predicts the relation $\nu_a \cdot \nu_p = \nu_0^2$. Any violation of special-relativistic time dilation would result in a deviation $\varepsilon(\beta)$ of the form

$$\frac{\nu_a \cdot \nu_p}{\nu_0^2} = 1 + \varepsilon(\beta) \quad (1)$$

When the lasers address different hfs-components of the dipole transition with frequencies ν_1 and ν_2, ν_0^2 in eq. (1) is replaced by $\nu_1 \cdot \nu_2$. Non vanishing values of the parameter $\varepsilon(\beta)$ can be interpreted in the frameworks of test theories [1, 2].

Figure 1 shows two types of spectroscopy signals we have recorded during a recent beam time in October 2010. The Λ-type signal (lower panel) is produced by coupling two levels of the hyperfine structure of the ground state of the metastable $^7Li^+$ ions via one excited level [3] and recording the fluorescence of the ion beam. With our setup we were able to measure the laser frequencies ν_a and ν_p with an absolute accuracy of 1 MHz which corresponds to a relative accuracy of $\Delta\nu/\nu = 2 \cdot 10^{-9}$. Together with the corresponding rest frequencies ν_1 and ν_2 [3], an upper bound for the parameter $\varepsilon(\beta)$ has been determined 25 times more accurate compared to the previous experiment at GSI [4]. The interpretation of this value in the frameworks of test theories [1, 2] shows that we were able to test SR with a four times higher precision than the currently leading experiment [5]. Within the experimental uncertainties no deviations from SR could be found. The upper part of figure 1 shows a signal which has been achieved via saturation spectroscopy where both lasers excite the same hfs transition. In this spectroscopy scheme a two level transition in the lithium ions is investigated and the dip can be observed only if both lasers interact simultaneously with the ions. This allows for signals which are narrower than those achieved with Λ spectroscopy. This method has been applied during this beam time for the first time at GSI and promises an even higher precision for the determination of the transition frequencies in the future.

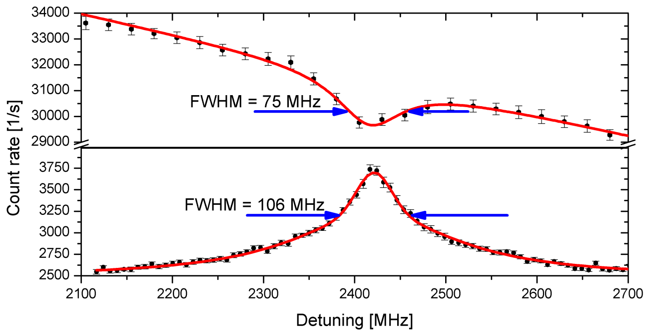

Figure 1. Two types of Doppler-free spectroscopy signals which can be used for determining laser frequencies with high accuracy. **Bottom**: Λ spectrum with good signal to noise ratio but large FWHM was used to calculate an upper bound of hypothetical deviations from SR. **Top**: Saturation spectroscopy signal which may provide higher precision in future experiments.

References

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