Spectroscopy of lithium ions at 34 % of the speed of light with sub-Doppler linewidth: *Towards a test of time dilation*

C. Novotny[a], B. Bernhardt[b], D. Bing[c], C. Geppert[d], G. Gwinner[e], T. W. Hänsch[b], R. Holzwarth[b], G. Huber[a], S. Karpuk[a], H.-J. Kluge[d], T. Kühl[d], W. Nörtershäuser[a,d], S. Reinhardt[b,c], G. Saathoff[b], D. Schwalm[c], M. Steck[d], T. Udem[b], and A. Wolf[c].

[a] *Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany*
[b] *Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany*
[c] *Max-Planck-Institut für Kernphysik, D-69029 Heidelberg, Germany*
[d] *Gesellschaft für Schwerionenforschung, D-64291 Darmstadt, Germany*
[e] *University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada*

We report on an experiment towards a test of time dilation for the theory of Special Relativity (SR). To this end, metastable $^7Li^+$ ions with a velocity (w) of 34 % of the speed of light (c) were stored in the Experimental Storage Ring at the Gesellschaft für Schwerionenforschung Darmstadt. This ion species offers a strong dipole transition in the optical regime ($\lambda_0 = 548.5$ nm) and a level scheme where spectroscopy with sub-Doppler linewidths is possible. In the experiment, lasers are aligned parallel- and antiparallel with respect to the ions' motion and fulfill the resonance conditions with the transitions for Λ-type spectroscopy. For the moving ion, the excitation frequencies $\nu_{p,a}$ in the laboratory reference frame are shifted with respect to the rest frequencies $\nu_{1,2}$ by $\nu_{p,a} = \nu_{1,2} \cdot \gamma \cdot (1 \pm \beta)$ where $\beta = w/c$. Multiplication of the two equations leads to $\nu_1 \cdot \nu_2 = \nu_a \cdot \nu_p$, if SR holds (i.e. $\gamma = (1-\beta^2)^{-(1/2)}$). In kinematic test theories [1],[2] deviations of SR are described by velocity-dependent test functions that can be expanded in powers of β^2. These lead i.a. to a slightly modified time dilation factor of $\gamma = \gamma_{SR} \cdot (1+2 \cdot \delta\alpha \cdot \beta^2 + (\delta\alpha + 2 \cdot \delta\alpha_2) \cdot \beta^4 + ...)$ where $\delta\alpha, \delta\alpha_2$ are test parameters that allow to quantify the deviations [3]. Previous experiments were either restricted to comparably low velocities (e.g. the precursor storage ring tests [4]) and thus limited to first-order deviations described by $\delta\alpha$; or, if the particle velocity allows for higher-order tests, the experiments suffered from poor frequency resolution [5]. We present a first step towards high precision experiments at high velocity and find time dilation to be consistent with the theory of SR to an upper bound of $|\delta\alpha_2| < 9 \times 10^{-6}$ for deviations to the order β^4. This means an improvement by a factor of 30 compared to [5].

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