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Storing keV negative ions for hours: Lifetime measurements in new time domains

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Synopsis We have used one of the cryogenic ion storage rings of DESIREE to measure the lifetime of the $^2P^o_{1/2}$ level in the sulfur anion to be 503 ± 43 seconds. This is orders of magnitude longer than any previously measured lifetime in a negatively charged ion.

We have measured the radiative lifetime of the $^2P^o_{1/2}$ level in $^{32}S^-$ using the cryogenic electrostatic ion-storage ring DESIREE (Double ElectroStatic Ion Ring ExpEriment) [1, 2, 3]. With its extremely good vacuum of a few times 10^{-14} mbar, DESIREE is capable of storing negative ions for very long times. Further, the cold environment makes it possible to study weakly bound systems, which rapidly would be photo-detached by the black-body radiation at ambient temperatures. The double-ring feature of DESIREE allows for studies of interactions between positive and negative ions down to very low center-of-mass energies. Here, however, we focus on laser experiments with ions stored in one of the rings.

The $^2P^o_{1/2}$ fine structure level in S^- is metastable and decays to the $^2P^o_{3/2}$ ground state through a slow magnetic dipole (M1) transition. The theoretically predicted lifetime of the upper state is 437 s [4]. Until now this has not been challenged by direct measurements as it has not been possible to store negative ions for sufficiently long times before. We utilized a laser probing technique photo-detaching small fractions of the ions in a stored beam by a series of laser pulses. By using two different laser wavelengths we monitored the neutral yield due to detachment of ions in the metastable state only and due to detachment of ions in both the ground- and metastable states. The inverse of the longer (1/e)-lifetime when both states were detached was taken as a measure of the residual-gas density. We repeated these steps at slightly elevated ring temperatures of 15-17 K, which gave higher residual-gas densities than at 13 K. In figure 1 we show the decay rates for different residual-gas densities. The intercept with the vertical axis gives the inherent spontaneous lifetime of the $^2P^o_{1/2}$ level (τ=503±43 s) [3]. This is by far the longest lifetime ever measured for a negatively charged ion. The difference from the theoretical prediction is 1.3σ showing that the multi-configuration Dirac-Fock method applied in [4] may be appropriate to describe the features of excited finestructure levels in atomic anions at this level of precision. The present results demonstrate the power of the new method and opens up for a broad survey of lifetimes of excited states in atomic ions in the time range from some tens of milliseconds to tens of minutes.

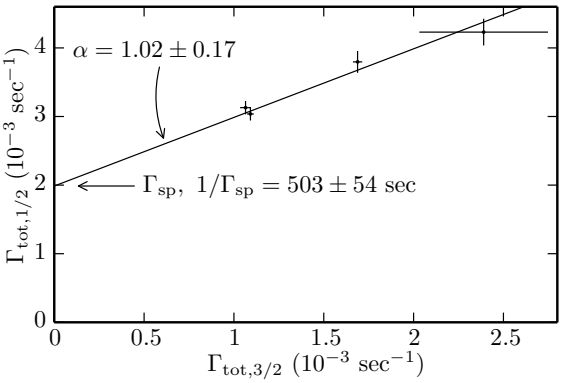

Figure 1. The measured decay rate of the $^2P^o_{1/2}$ level (ordinate) plotted with measured decay rate of the $^2P^o_{3/2}$ level (abscissa) in S^- [3].

References

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