Fine Structure of Heliumlike and Hydrogenlike Ions by Fast-Beam Laser Spectroscopy

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Since the last ICAP we have completed precision measurements of the $1s2p\ ^3P_{2,F} -^3 P_{1,F'}$ fine and hyperfine structure in $^{19}F^{7+}$[1], and of the $1s2p\ ^3P_0 -^3 P_1$ fine structure in $^{24}Mg^{10+}$[2]. The technique used foil-stripped 1-2 MeV/amu ion beams magnetically deflected to be co-linear with a high power, line tunable, continuous wave CO_2 laser. The interaction took place at the intracavity focus of an extension to the usual standing-wave laser cavity. The laser induced magnetic dipole transitions from the longer lived $1s2p\ ^3P_2$ and $^3P_0$ levels, respectively, to the shorter lived $1s2p\ ^3P_1$ level. The transition was observed by detecting the subsequent soft x-ray decay to the groundstate using a proportional detector. The resonances were scanned by varying the ion beam velocity to vary the Doppler shift. In the case of fluorine, the doppler shift was accounted for by using co- and counter-propagating laser beams. For magnesium, the transition occurs near 12.0 μm and could only be reached by operating the laser on the hot band of $^{12}C^{16}O_2$, using the co-propagating beam. Here we accounted for the Doppler shift by calibrating the analysing magnet, which determines the beam velocity, using previously measured laser induced resonances in $^{14}N^{5+}$ [3].

The results of these fine structure measurements, together with our previous result for the $1s2p\ ^3P_0 -^3 P_1$ fine structure in $^{14}N^{5+}$, see table 1, provide precision tests of higher-order corrections to the theory of $n = 2$ fine structure in heliumlike ions. This theory may be used to obtain a new "Atomic Physics" value for the fine structure constant from comparison of theory and experiment for the fine structure of helium[4, 5].

Table 1: Results for $1s2p\ ^3P_J -^3 P_{J'}$ fine structure intervals in heliumlike ions obtained by fast beam laser spectroscopy. Units cm^{-1}.

Ion	Reference	$^3P_0 -^3 P_1$	$^3P_1 -^3 P_2$
$^{14}N^{5+}$	[3]	8.6707(7)	
$^{19}F^{7+}$	[1]		957.8730(12)
$^{24}Mg^{10+}$	[2]	833.133(15)	

For hydrogenlike ions there is now considerable interest in obtaining measurements of the Lamb Shift with sufficient precision to test binding corrections to the two-loop self-energy[6, 7, 8, 9]. Better understanding of these QED contributions will be required for obtaining improved values of the Rydberg constant and the proton size from precision two-photon spectroscopy of atomic hydrogen[10]. Because of the Z-scaling of the terms of interest, measurements on moderate Z ions, though less precise than the measurements on hydrogen, can provide useful tests of the theory. Nevertheless, this requires an order-of-magnitude improvement over the precision of previous fast-beam laser Lamb shift measurements[11]. Experimental conditions appear especially favorable for a fast-beam laser resonance measurement of the $2S_{1/2} - 2P_{3/2}$ (Fine structure - Lamb Shift) interval in hydrogenlike nitrogen. This transition occurs at a wavelength of approximately 12.0 μm. N^{6+} ions in the $2S_{1/2}$ level, mean lifetime 1.03 μs, are prepared by foil stripping a 1-3 MeV/amu beam of nitrogen ions from a tandem Van de Graaff accelerator to the bare nucleus, followed by single electron capture in a second thin foil or gas target. A continuous wave CO_2 laser induces transitions to the $2P_{3/2}$ level, mean lifetime 0.66 ps. The transition is detected through the 500 eV x-ray photon emitted in the decay to the groundstate.

We have carried out an exploratory measurement using our existing high power CO_2 laser system operating on the hot band of $^{12}C^{16}O_2$. Excellent signal rates have been achieved. Development of a system with careful control of systematics is in progress. This will use two scientific lasers with $^{13}C^{16}O_2$ or $^{14}C^{16}O_2$ gas fills.

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