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Absolute Wavelength Measurement and Fine Structure Determination in ^{7}Li II*

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The energy levels of two-electron atoms continue to provide rigorous tests of relativistic quantum theory, and of correlation effects within a multi-particle system. These interactions are determined perturbatively, with several approximations, and theoretical results often differ. It is critical to provide precise measurements of absolute wavelengths connecting these atomic energy levels to obtain a resolution of the precision of the different parts of such complex calculations.

Recently, high-precision measurements have been carried out in high nuclear charge (Z) ions using various fast beam spectroscopy techniques, principally to study the higher order Z-correction terms in the relativistic Breit and QED interactions. The measurements have been made principally of the 1s2s ^3S - 1s2p ^3P transitions for ions of Z=10 up to 26. The best of these measurements test the QED corrections at a level of 2 parts in 10^4, with absolute wavelength accuracies of about 5 parts in 10^6. For lower Z systems, the relativistic corrections are smaller, since they scale as Z^4 and higher, and non-relativistic correlations become larger, since they scale with as Z^{-1} and lower. Relativistic correlations can scale with all powers of Z, and hence some should be measurable for many different ranges of Z. The application of laser techniques can lead to much higher precision in atomic wavelength measurements. Clearly, these are most easily applied for low Z ions where the 1s2s ^3S - 1s2p ^3P transitions are above 2000Å.

In this work, we report a high precision optical measurements in the 1s2s ^3S - 1s2p ^3P multiplet of Li II using fast-beam laser spectroscopy. A collinear interaction using both parallel and antiparallel laser and ion beams allows both for precise elimination of large Doppler shifts, and for a strong kinematic narrowing of the observed resonances, as compared with thermal beam experiments. The wavelengths of the observed resonance fluorescence radiation are determined by comparing them with simultaneously recorded saturated absorption profiles of molecular iodine hyperfine components. In turn, the absolute wavelengths of the iodine lines are obtained from precisely calibrated Fabry-Perot etalon fringes in a separate experiment. The final precision of the Li II wavelengths is 5 parts in 10^9, which is at a level of precision of 80 ppm of the QED corrections in the transition.

A schematic of the fast beam experimental arrangement is shown in Fig. 1. Data were taken in several series of measurements of σ_+ and σ_-, the fluorescence wavenumbers in the parallel and antiparallel geometries. The alternating sets of data were corrected for a slow temperature-dependent drift of the accelerator voltage, which was of the order of 1-2 volts per hour in 50 kilovolts. The resonance wavenumber is then given by $\sigma_o = \sqrt{\sigma_+ \cdot \sigma_-}$. This is independent of the ion beam velocity, provided that it is stable to the required precision during the time of the measurements. The absolute values of the I_2 lines used in the experiment (one for each σ_+ and σ_+ measurement) were measured using a 0.5m and a 1.0m temperature-stabilized (within 10^{-3}K) interferometer.

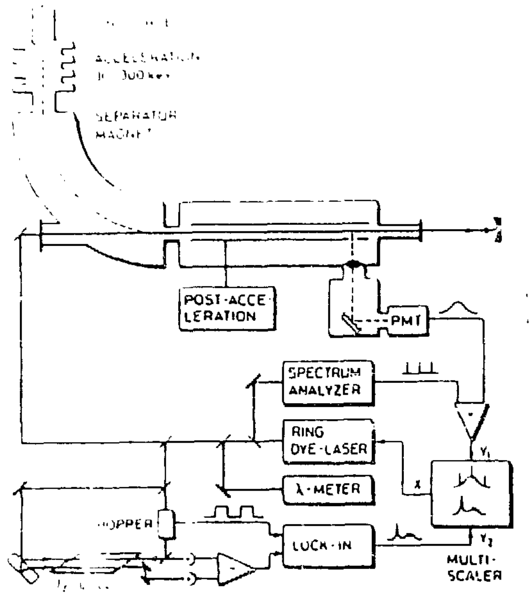

Fig. 1. The experimental arrangement for the laser excitation of the fast (50 keV) Li^+ beam. The ring dye laser is tuned successively to the resonance fluorescence for parallel and anti-parallel excitation, all other parameters remaining fixed, with outputs from the spectrum analyzer, the I_2 absorption cell and the λ-meter being measured simultaneously.

Since the hyperfine structure is calculated to a precision better than our experimental accuracy (±3 MHz), we can use theoretical values to derive three separate parameters from our data. These three are the two fine structure intervals, Δ_{02}, and Δ_{21}, of the 1s2p ^3P state, and the absolute wavelength of the transition from the center of gravity of the 1s2s ^3S state, and the center of the 1s2p $^3P_0$ state. Our preliminary results are shown below, and compared with other experimental and theoretical values.

Table I. All measurements in cm^{-1}, with accuracies given in parentheses. The first 5 figures are omitted in the last 3 columns for σ_0.

Interval	This work	Ref. 1	Ref. 2	Ref. 3 (Theory)
σ_0	18231.30200(10)	-.3028(8)	-.3030(12)	-.313
Δ_{02}	3.10265(10)	3.1028(8)	3.1051(12)	3.118
Δ_{21}	2.08730(10)	3.0906(8)	2.0897(12)	2.086

We conclude that our measurements are consistent with previous measurements. The improved accuracy is due mostly to narrower line profiles in the fast beam geometry and the absolute calibration against I_2. Theory is also consistent, but at a much lower level of accuracy, being limited both by the non-relativistic energy calculations (± 0.001 cm^{-1}), and also by a relativistic correlation term (± 0.01 cm^{-1}). We expect that similar techniques are applicable for neighboring Z elements.

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