precision spectroscopy of Li I & II

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Li⁺ and neutral lithium are among the simplest atoms containing the electron-electron interaction. These systems provide information about quantum electrodynamic (QED) contributions to the state energies that scale to lowest order as $Z^4\alpha^3$ times the Rydberg energy, where Z is the nuclear charge and α is the fine structure constant. Hence, QED effects are more prominent in lithium than in either helium or hydrogen. Recent theoretical advances using the variational technique have enabled Li I & II to be used to test QED [1]. In addition, the relative nuclear radii can be determined more accurately than is possible from nuclear scattering experiments.

Our experiments use a laser to excite either an ion or neutral atomic beam. The laser is frequency modulated at using an electro-optical modulator. The modulation frequency is specified to better than one part in 10^6 using a frequency synthesizer. The laser frequency is scanned across the resonance and fluorescence is detected by a photomultiplier. Each transition is then excited by the various frequency components of the laser beam yielding a multiple peaks separated by the modulation frequency. This enables the laser frequency scan to be calibrated and checked for linearity. This technique does not rely on the calibration of a Fabry Perot interferometer by a national standards laboratory.

In the case of Li⁺, the metastable 1s2s 3S_1 state is produced using an electron beam to ionize neutral lithium atoms. The 1s2s $^3S_1 \rightarrow 1s2p$ $^3P_{0,1,2}$ transition at 548 nm is then excited using a dye laser [2]. Our results for the hyperfine splittings of the 1s2p $^3P_{1,2}$ states are an order of magnitude more precise than measured previously and are in excellent agreement with theory. The results for the 1s2p $^3P_{1-2}$ fine structure resolve a 17σ discrepancy between two other experiments as shown in Table 1.

Value (MHz)	Reference
62,667.4 ± 2.0	Expt. [3]
62,678.41 ± 0.65	Expt. [4]
62,679.46 ± 0.98	Expt. [2]
62,679.4 ± 0.5	Theory [1]

Table 1. ⁷Li⁺ 1s2p ³P₁₋₂ Fine Structure Interval

In the case of neutral lithium, a diode laser excited the D lines of ^{6,7}Li. The transmission of part of the laser beam through an etalon was monitored to correct for the nonlinearity of the laser scan. The results for the ^{6,7}Li 2S_{1/2} and 2P_{1/2} hyperfine splittings agree very well with the best existing data while those for the D1 isotope shift and ^{6,7}Li

fine structure splittings disagree with data obtained by a previous laser atomic beam experiment [5,6]. Our result for the D1 isotope shift is very close to the value computed using Hylleraas variational theory [7]. The 6,7 Li isotope shift can be used to determine the relative nuclear radius of these two isotopes. The results found using a number of experiments including a recent one that studied the 6,7 Li 2S \rightarrow 3S transition are not entirely consistent with each other [8].

Work is underway to improve the aforementioned measurements. In the case of Li⁺, an optical double resonance experiment will be used whereby a laser first excites the $1s2p\ ^3P_1$ state. The microwave frequency required to make a transition to the $1s2p\ ^3P_2$ state will then be measured. At least an order of magnitude improvement in the fine structure splitting is likely. Eventually it may be possible to measure the larger $1s2p\ ^3P_1 - 1s2p\ ^3P_0$ interval which would be of interest for precisely determining the fine structure constant.

In the case of neutral lithium, it would be desirable to repeat our experiment using a ring dye laser as this has an order of magnitude smaller scanning nonlinearity than a diode laser. The eventual goal is to measure the isotope shifts of the radioactive species ^{8,9,11}Li. ¹¹Li in particular is of interest as it is believe to have two so called halo neutrons. It is proposed to use an accelerator at Argonne laboratory to load the short lived lithium isotopes into a magneto-optical trap in order to generate a sufficient fluorescent signal [9].

References

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