W. Ansbacher, Y. Li and E.H. Pinnington

Lifetime measurements using pulsed laser excitation of fast ion beams

ABSTRACT

A review is presented of the Edmonton program of lifetime measurements using pulsed laser excitation of fast ion beams. Since 1985 measurements have been completed for the 3p and 4p levels of Mg II and Ca II respectively, the precision of these measurements being about 1%. Excellent agreement is found with the calculations of Theodosiou. Recently we have begun a more extensive study of some resonance levels in Fe II. Preliminary results for the levels of the z $^6G^0$ term show agreement with (less precise) previous experiments but differ significantly from the results of calculations by Fawcett and Kurucz.

INTRODUCTION

In 1985 we reported the first measurements using pulsed laser excitation of the 4p levels of Ca II. The precision of those measurements was about 5%, the major limitation being the high level of laser scattered light. Since then we have constructed a new chamber, designed both to minimize this problem and to increase the collection efficiency of the detection system. The lifetimes obtained using the new chamber had a precision of about 1.0%. They were in agreement with the earlier experiment but were significantly longer than all the calculations available at that time. Shortly after these results were published, a calculation by Theodosiou (1989) gave results in excellent agreement with our experiments. These results are summarized in Table 1.

Table 1. Summary of Beam-Laser Measurements of the Lifetimes (in ns) of the 4p Levels of Ca II. (Uncertainties shown in parentheses)

Reference	j=1/2	j=3/2
Ansbacher et al(1985)	6.96(.35)	6.71(.25)
Gosselin et al(1988)	7.07(.07)	6.87(.06)
Theodosiou (theory,1989)	7.045	6.852

STUDIES USING FREQUENCY-DOUBLED RADIATION

Following the success of our Ca II measurements, we decided to attempt a study of the 3p levels of Mg II. Here the excitation wavelengths (279.6 and 280.3nm) require the use of a frequency-doubling crystal and, prior to the experiment, it was not clear that our Lumonics EPD-330 dye laser system would deliver sufficient power for a useful signal. In the event, we were able to measure the lifetimes of the 3p levels to a precision of about 1%, these results showing agreement with the most recent calculation.

Table 2. Lifetimes of the Mg II 3p Levels(ns) (Uncertainties shown in parentheses.)

Reference	j=1/2	j=3/2
Ansbacher et al(1989)	3.854(.030)	3.810(.040)
Theodosiou and Curtis (theory, 1988)	3.872	3.842

The close coincidence of the 3s-3p and 3p-3d transition wavelengths in Mg II permits two further experiments. Firstly, two-step excitation of the 3d(3/2) level is possible by reflecting the laser beam back along its path through the chamber. The Doppler shifts are arranged so that the 3s-3p(1/2) transition is excited by the first passage of the laser beam and the 3p(1/2)-3d(3/2) transition is excited by the return passage. Secondly, direct two-photon excitation of the 3d(5/2) level is possible using a single passage of the laser having a wavelength which differs by only 0.13nm from that of the 3s-3p(3/2) transition. Further details of these two experiments are available elsewhere (Ansbacher et al, 1989). The important point here is that they are possible using our equipment, which provides strong evidence that we are still saturating the single-photon excitations at 280nm.

MEASUREMENTS FOR SINGLY-IONIZED IRON.

There are two main factors that make measurements in Fe II more difficult than those just discussed. Firstly, the excitation wavelengths are even shorter. Our preliminary measurements indicate that at these wavelengths we are not able to saturate the excitation transition completely. This has the serious consequence that the observed signal depends on the laser power, which is difficult to maintain constant over the million or so pulses required for one decay curve. Secondly, the lowest configuration of Fe II contains many levels within leV or so of the ground state. Since only a small fraction of the ion beam is in a given level, the background contribution from gas excitation and laser scattering is larger for a given signal level than in our previous experiments. The measurements we have made to date for the z $^6D^o$ levels are summarized in Table 3.

Table 3. Lifetimes of the Fe II z $^6D^o$ Levels. (Uncertainties shown in parentheses.)

J-Value	Lifetime (ns) (1)	(2)	(3)	(4)	(5)
9/2	3.78(.05)	3.7(.2)	3.9(.2)	2.97	3.41
7/2	3.79(.06)	3.8(.3)	4.0(.2)	2.99	3.43
5/2	3.75(.07)	3.8(.3)	4.0(.2)	2.99	3.44
3/2	3.89(.08)	3.7(.2)	3.9(.3)	3.00	3.45
1/2	3.94(.08)	3.8(.3)	4.0(.3)	3.00	3.46

(1) Fast beam-laser excitation (This work).
(2) Laser-ind. fluor. (Schade et al, 1988).
(3) --------- (Hannaford and Lowe, 1983).
(4) RHF calculation (Fawcett, 1987).
(5) Semi-emp. calculation (Kurucz, 1981).

The higher uncertainties for lower j-values reflect the progressively smaller fraction of the ion beam that is in the lower state involved in the excitation. Even though these measurements are rather preliminary, it is clear that our technique gives results in agreement with previous, less precise, laser measurements. All the experiments differ significantly from the calculations by Fawcett and Kurucz.

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AUTHORS' ADDRESS

Department of Physics,
University of Alberta, Edmonton, Alberta,
Canada, T6G 2J1.