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LETTER TO THE EDITOR

Measurement of the scalar polarizability of very highly excited states of caesium

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Abstract. First results on the scalar polarizability α_0 of a number of very highly excited p states of Cs ($40 \leqslant n \leqslant 60$), produced by one-step photoexcitation with frequency-doubled dye-laser radiation, were obtained by means of electrostatic beam deflection in a two-wire type electric field. Enormous polarizabilities of $\alpha_0/4\pi > 10^9$ Å^3 were measured; the dependence of the polarizability as a function of the principal quantum number n was found to be in agreement with the expected n^7 behaviour.

The energy change of an atom exposed to a weak electric field of strength E is given by the Stark Hamiltonian

$$H_{\text{stark}} = -\frac{1}{2}\left(\alpha_0 + \alpha_2 \frac{3J_z^2 - J(J+1)}{J(2J-1)}\right)\epsilon_0 E^2 \tag{1}$$

where α_0 and α_2 are respectively the scalar and tensor polarizabilities (Khadjavi *et al* 1968), J_z is the projection of the total electronic angular momentum J in the direction of the electric field, and ϵ_0 is the vacuum permittivity. In strong electric fields the Stark effect cannot be treated as a perturbation to the fine-structure interaction and, consequently, J and J_z of equation (1) have to be replaced by the orbital angular momentum L and its projection L_z. In equation (1) the α_0 term describes the average energy shift of all sublevels and the α_2 term the Stark level splitting. Both effects are expected to scale with n^7 (Wing *et al* 1973).

The Stark effect of excited states of alkali atoms has been of great interest recently (Hogervorst and Svanberg 1975, Harvey *et al* 1975, Fabre and Haroche 1975, Littman *et al* 1976). Most spectroscopic measurements have only produced data on the tensor polarizability α_2 and have covered only two or three adjacent n values. Fabre and Haroche (1975) measured α_2 for the sodium d states with $n = 10, 11, 12$ by quantum-beat spectroscopy and obtained very large values in accordance with the n^7 scaling. Experimental data of the scalar polarizability, α_0, are available for the s ground states of all alkali metals (Molof *et al* 1974, Hall and Zorn 1974) and the 4d and 5s states of sodium (Harvey *et al* 1975).

Here we report the first results of direct measurements of the scalar polarizability of very highly excited p states of caesium. We measured the beam deflection in an inhomogeneous electric field; the deflection averaged over the unresolved Stark sublevels is a measure of α_0. Production and detection of the very highly excited atoms was reported in a previous letter (van Raan *et al* 1976); the arrangement is shown in

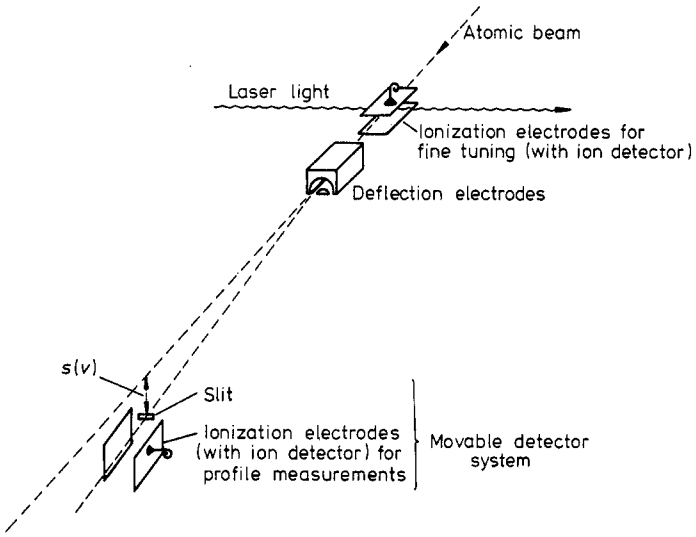

Figure 1. Experimental arrangement (not to scale).

figure 1. An atomic beam of caesium was crossed by a laser beam (frequency-doubled, flash-lamp pumped dye laser, Chromatix CMX–4). Fine tuning of the selected state was done by optimizing the ionization signal resulting from a pulsed ionizing electric field applied in the excitation region about 1 μs after the laser pulse. The excited atoms passed through a 'two-wire type' inhomogeneous electric field of the same geometry as that used by Chamberlain and Zorn (1963) for determining α_0 of the ground-state alkali atoms; its geometry is given in figure 3 of their publication.

A parallel atomic beam passing through the deflection field of length l is detected at a distance l' away from the midpoint of the deflection field. The transverse displacement of the beam position in the detector plane is given by

$$s(v) = \alpha_0 \epsilon_0 E \frac{\partial E}{\partial z} ll'/mv^2 \tag{2}$$

where m is the atom mass and v the velocity. From the electrode geometry, it follows that

$$E \frac{\partial E}{\partial z} = GU^2 \tag{3}$$

where U is the voltage applied to the deflection electrodes and G is a geometric factor. We have $G = 4{\cdot}23 \times 10^6\ \mathrm{m}^{-3}$ (Chamberlain 1961), $l = 0{\cdot}050$ m and $l' = 0{\cdot}295$ m. Beam profiles were measured with several different deflection voltages for each state. Measurements are not yet accurate enough for a complete theoretical analysis of the beam-profile function. For a first evaluation we took the measured displacement of the peak of the profile at small deflection field strengths (one-third of the field for quenching) where the Stark effect is assumed to be still quadratic.

The undeflected beam has a width of 2 mm at the detector position. The detector assembly is movable perpendicular to the beam. It consists of a slit aperture of 0·3 mm width behind which the very highly excited atoms are ionized in an electric

field and the ions detected by a channel electron-multiplier. The assembly also contained an iridium-band Langmuir–Taylor detector.

For the measurement of one beam profile the slit aperture was scanned across the beam in steps of 0·5 mm. In each position the Cs ions were counted for 500 laser shots. At most 5 ions were detected per laser shot. As dye we used Kiton Red S dissolved in water. The frequency-doubled light had about 0·5 kW peak power and a pulse length of about 1 μs. Frequency tuning was achieved by a birefrigent filter and a high finesse etalon. The linewidth was about 0·3 cm^{-1}.

The very highly excited atoms travel about 0·3 m between excitation and detection at velocities of the order of 300 m s^{-1}; this indicates that the lifetime of the high n states is not significantly smaller than 1 ms. Spectroscopic data confirm this. A lifetime of about 7 ms for the 50 p state, for example, follows from computing the lifetime of the 17 p state from the absorption oscillator-strength data of Exton (1976) and scaling proportional to n^3.

The n dependence of the measured scalar polarizabilities is shown in figure 2. The polarizabilities α_0 and α_2 have the dimension (length)^3 and are customarily stated in units of $Å^3 = 10^{-30}$ m^3; in the CGS system the numerical values are different, namely, $\alpha(\text{CGS}) = \alpha/4\pi$.

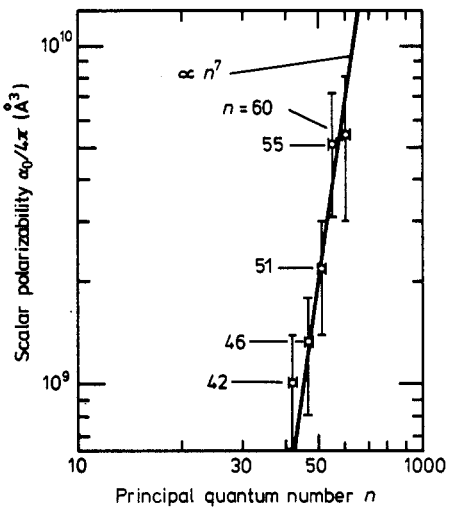

Figure 2. Measured scalar polarizabilities of p state caesium atoms versus principal quantum number. Plotted is $\alpha_0/4\pi$ which is numerically equal to α_0(CGS). The error bars give the relative errors. The absolute uncertainty is estimated to be about ±50%.

Khadjavi *et al* (1968) calculated for the $7\,^2P_{3/2}$ state of Cs $\alpha_0/4\pi = 5{\cdot}38 \times 10^3$ Å. This value, scaled proportional to n^7 from $n = 7$ to $n = 50$, yields $\alpha_0(50\,\text{p})/4\pi = 5 \times 10^9$ $Å^3$ in good agreement with our measurements. Khadjavi *et al* also calculated and measured $\alpha_2(7\,^2P_{3/2})$ and obtained a value which is an order of magnitude smaller than α_0.

In order to increase the accuracy of the α_0 measurements and to resolve the different Stark sublevels for determining α_2, we are preparing measurements with velocity selection by gating the detector such that only a small flight-time window is utilized.

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