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High-Resolution Stark Spectroscopy of Ba Highly-Excited States by Diode Laser Technique

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Abstract

High-resolution atomic-beam laser spectroscopy has been performed to study Stark effect of Ba atom. Stark spectra have been observed at various electric fields for Ba highly excited states. The scalar polarizability of the transition from $6s5d^3D_2$ to $5d6p^3F_3$ at 728.0 nm and the tensor polarizability of the $^3F_3$ level have been determined for the first time, to be α_s = −89.8 (12) kHz/(kV/cm)^2 and α_t = −133.7 (20) kHz/(kV/cm)^2, respectively.

Keywords

Stark Effect, Scalar and Tensor Polarizabilities, Ba Atom, $6s5d^3D_2$ - $5d6p^3f_3$ Transition, High Resolution, Laser Spectroscopy

1. Introduction

Stark effect, the shift and splitting of atomic spectral lines by an external electric field, was discovered in 1913. The tensor and scalar polarizabilities have become interesting and heightened properties in recent years due to several applications, such as the development of next-generation optical atomic clocks, optical cooling and trapping schemes, the study of long-range interactions, and atomic transition rate determinations [1]. And the research could supply information on the study of electric dipole moment (EDM) of electrons [2] [3]. The study of parity nonconservation (PNC) in atoms even may yield a clue to "new physics" [4] [5]. In the other hand, theoretical calculations of electric dipole polarizabilities have achieved a remarkable development; low-lying levels of Ba have been accurately calculated with *ab initio* calculation [6]. The two-valence atom Si^{2+} calculated by configuration interaction + all-order method also shows a good agreement with experimental results [7]. Properties of energies, lifetimes, hyperfine constants, multipole polarizabilities, and blackbody radiation shift in ^{137}Ba II have been correctly calculated with relativistic many-body calculation [8]. Calculations for highly excited states are expected. Thus precise experimental data on highly excited states will provide a further test of theoretical calculation.

However, experimental polarizability data of two-electron atoms at highly excited states were rarely reported. This is due to the difficulties of generating high electric field and performing high resolution spectroscopy at highly excited states. In this paper, we report high-resolution Stark spectroscopy for Ba highly excited states using the diode laser technique together with a collimated atomic beam.

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2. Experimental Procedure

The experimental setup is similar with that used in previous studies of K, Rb, and Yb [9]-[11]. The metastable level $6s5d^3D_2$ was populated by a discharge burning in barium vapor directly in front of the oven hole. A high-resolution atomic beam spectroscopy was performed to measure atomic Stark spectra, with a voltage applier capable of generating strong and static voltage up to 26.0 kV corresponding to a field strength of 43.4 kV/cm. A commercial tunable diode laser (TEC520) with an output power of 80 mW covered the wavelength range of 725 - 736 nm. The line width of the laser was smaller than 1 MHz. A confocal Fabry-Perot interferometer (FPI) with a free spectral range of 300 MHz was used to determine relative frequency. A fluorescence induced by laser beam was measured with a photomultiplier.

3. Results and Analysis

In the absence of the hyperfine interaction, the Stark shift $\Delta\omega$ can be written as [12]:

$$\Delta\omega = -\frac{1}{2}\left(\alpha_s + \alpha_t \frac{3m_J^2 - J(J+1)}{J(2J-1)}\right)E^2 \tag{1}$$

where J is the quantum number of the total electronic angular momentum and m_J is the projection of J on the direction of the electric field. E is electric field strength. α_s and α_t are traditionally called the scalar and tensor polarizabilities, respectively. It is obvious that the number of peaks by the Stark splitting is depending on them_J. The Stark shift and splitting are proportional to the square of the electric field, thus we can get tensor and scalar polarizabilities from measured $\Delta\omega$.

Stark spectra were observed for the $6s5d^3D_2 - 5d6p^3F_3$ transition at 728.0 nm. The **Figure 1** shows the measured Stark spectrum at 43.4 kV/cm together with that at 0 field for the 728.0 nm transition. The strongest peak is corresponding to ^{138}Ba with the 71.7% abundance. No hyperfine structure shows in this isotope owing to nuclear spins 0. The spectrum is found to shift to right by the electric field, *i.e.*, the larger transition frequency, and 4 spectral lines are clearly observed. The background is due to the scattering of the laser beam from the electrodes. The transition was precisely measured at the range of electric field from 16.7 to 43.4 kV/cm. A good linear relationship between the shift or splitting and the square of electric field was confirmed.

The results obtained are given in **Table 1**. The scalar polarizability of the transition from $6s5d^3D_2$ to $5d6p^3F_3$ at 728.0 nm and the tensor polarizability of the $^3F_3$ level have been determined for the first time. Uncertainties of

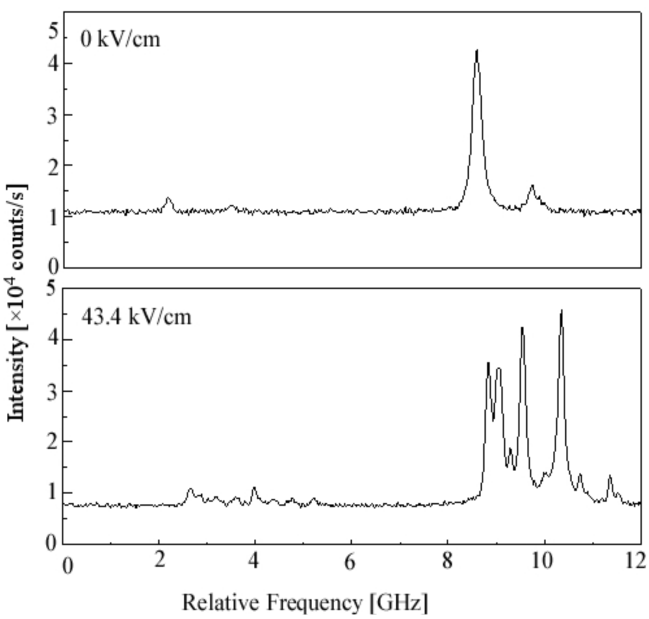

Figure 1. Observed Stark spectra of the 6s5d3D2 − 5d6p3F3 transition at 728.0 nm in Ba.

Table 1. Determined scalar and tensor polarizabilities for Ba.

Transition	α_s (kHz/(kV/cm)^2)	α_t (kHz/(kV/cm)^2)
$6s5d\,^3D_2 - 5d6p\,^3F_3$	−89.8 (12)	−133.7 (20)

results are mainly from the uncertainty of the distance between the two electrodes, and the uncertainty of peak fit.

4. Conclusion

The Stark effect of highly excited states in Ba has been investigated using the diode laser. The diode laser with its lower cost, together with the atomic beam, has been proved to be a powerful technique to perform high resolution atomic spectroscopy. The fundamental atomic data such as the electric polarizabilities can be derived from spectroscopic measurements. In this paper, the scalar polarizability of the $6s5d\,^3D_2 - 5d6p\,^3F_3$ transition in Ba and the tensor polarizability of the $^3F_3$ level have been determined for the first time and such kinds of atomic data at highly excited states will provide a critical challenge to theoretical calculations.

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