Observation of the ^3F metastable states of neutral barium

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(Received 2 June 1975)

The ^3F metastable states of the $5d^2$ configuration of neutral barium have been observed in an atomic beam. As far as can be determined from the literature, these states have not been observed previously. Their g factors have been measured, and the transmission characteristics of the apparatus indicate a lifetime of at least 10^{-3} sec.

I. INTRODUCTION

Most low-lying energy levels of neutral atoms have been observed and their energies measured. However there are some atoms in which energy levels have been predicted theoretically, but for one reason or another they have not been observed experimentally. Neutral barium is one of these, and it is the purpose of this paper to report the observations of three metastable levels that apparently have not been seen previously.

The new levels belong to the $5d^2$ configuration and have the designation ^3F. The levels have been predicted theoretically,[1,2] and two other levels of this configuration, the ^3P and ^1D, have been observed.[1] Barium is unique among the alkaline earths in that the $5d^2$ configuration lies low in energy and can therefore give rise to metastable states whose decay to lower states is forbidden by optical-dipole selection rules.

The low-lying energy levels of Ba I are shown in Fig. 1. The ^3F levels of interest here are labeled $5d^2$ and are shown as a single level since the triplet spacing is not known. All three components of the the triplet have been observed in this work, but it was not possible to measure their separation with the present apparatus. An experiment to determine the energy of these levels is being planned using a dye laser for excitation.

II. EXPERIMENT

The technique used in this work was that of atomic-beam magnetic resonance.

The apparatus used has been described previously by Schmelling,[3] and the method of metastable production has been discussed by Heider and Brink.[4] Briefly, the metastables were produced in a low-impedance discharge in the effusion orifice of the atomic-beam oven. The beam was detected by ionization on a hot wire followed by mass analysis, and the number of ions produced per unit time was measured as a function of the rf frequency applied to the hairpin with the results stored in an on-line computer. Signal-to-noise ratio was enhanced by means of digital signal averaging.

An rf scan at low magnetic field is shown in Fig. 2. The resonances labeled $^1D_2$, $^3D_2$, and $^3D_3$ are in the metastable fine-structure states of the $6s5d$ configuration, and the resonances marked $^3D_3$, $F=\frac{7}{2}$ and $^3D_3$, $F=\frac{5}{2}$ are hyperfine resonances in this same configuration. The other two small resonances are in the $^3F_4$ and $^3F_3$ fine-structure states of the $5d^2$ configuration.

The $^3F_2$ component of the $5d^2$ configuration has a smaller g factor than the other components, and it doesn't show on the scan in Fig. 2. It is shown at a field of about 100 Oe in Fig. 3. Also shown is a resonance in the $^3D_3$ state of the $6s5d$ configuration which is observed owing to a small amount of second harmonic present in the rf. This turns out

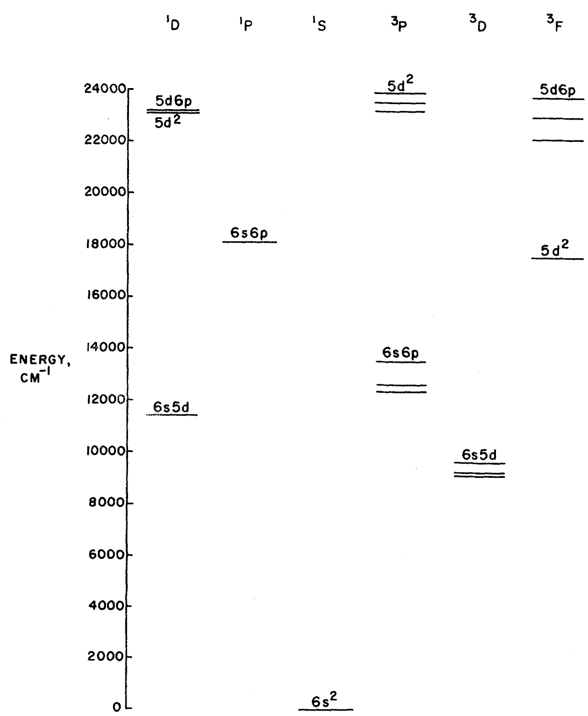

FIG. 1. Low-lying energy levels of Ba I. Newly observed levels are marked $5d^2$ ^3F. The triplet is indicated by one level since triplet spacing is unknown.

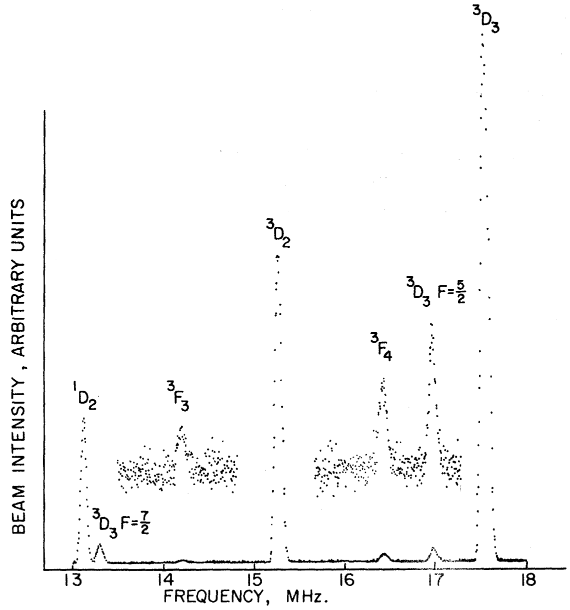

FIG. 2. rf resonances observed in an atomic beam of barium at a magnetic field of approximately 10 Oe. Upper trace is magnified by a factor of 10.

to be convenient since it provides a calibration of the magnetic field. The third resonance shown is in a hyperfine state.

The g factors of the ^3F states have been measured and they are shown in Table I. Also shown is the Landé g factor for each state. It can be seen that there is good agreement except for a small shift in the g factor observed for the $^3F_2$ state. Since more data were taken for this state, the statistics are better. Instability in the magnetic field used prevented a more precise determination

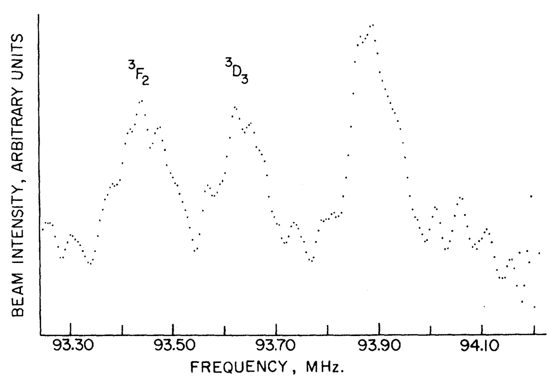

FIG. 3. rf resonances observed at a magnetic field of approximately 100 Oe.

TABLE I. g factors of the $5d^2\,^3F$ states of neutral barium. Errors quoted are standard deviations of the data.

State	Experimental g factor	Landé
$^3F_4$	1.2503 ± 0.0018	1.2506
$^3F_3$	1.0838 ± 0.0009	1.0835
$^3F_2$	0.6654 ± 0.0002	0.6659

of the g factors.

It can be seen from the data presented that the intensities of the resonances in the ^3F states are comparable to the intensities in the hyperfine resonances. All of these resonances are about 30 times weaker than resonances in the fine-structure components of the $6s5d$ configuration. Although resonance intensities are difficult to compare, this allows an estimate of the intensity of the ^3F states in the beam to be set at about 1% of the total beam intensity. The fact that the ^3F states are seen at all indicates that their lifetime against decay must be at least as long as the flight time through the beam apparatus, which is about 10^{-3} sec.

Although this experiment cannot determine the energy of the $5d^2\,^3F$ states with respect to other states of neutral barium, it has been placed theoretically[2] at about 17 500 cm^{-1} which is above the $6p\,^3P^o$ states. The ^3F states should serve as terminating states for a number of optical transitions from higher-lying triplet states.

The demonstration of the presence of these states in a beam produced by a discharge in barium vapor could be of importance in several areas of current interest. Laser action in barium vapor has recently been observed,[5] and it may be that other lasing transitions can be shown to exist which terminate on the ^3F states. It has been suggested that the strongest lasing transitions are those terminating on metastable states, and this has been shown to be the case in barium for the lasing transitions that have been observed. For some years now, clouds of barium vapor have been released in the upper atmosphere in order to study electric and magnetic fields present there. The formation of ionized barium in the clouds has been attributed to photoionization of the $6s5d\,^1D$ and ^3D states of neutral barium by ultraviolet light from the sun. Since the ^3F states lie above the D states, it should be easier to photoionize them, and they may be important in the understanding of this phenomena. Because of their larger excitation energy, they would probably be present in lower abundance in the barium cloud, but if their photoionization cross section was large enough, they could still contribute to the formation of ionized barium.

ACKNOWLEDGMENTS

The authors express their appreciation to Stephan M. Heider for assistance with this experiment. Computation was supported by the State University of New York at Buffalo Computating Center.

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