A High Resolution Study of the Transitions $4f^7 6s^2 \rightarrow 4f^7 6s 6p$
in the Eu I-Spectrum

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Eight transitions in the Eu I-spectrum connecting the ground state with configuration $4f^7 6s^2$ with states of the configuration $4f^7 6s 6p$ were studied with high resolution laser-atomic-beam spectroscopy. CW dye lasers operating in the wavelength regions 435–470 nm and 560–630 nm were used for this study. New data for the hyperfine structure in $^{153}\text{Eu}$ were obtained as well as new and more accurate values for the isotope shifts between $^{151}\text{Eu}$ and $^{153}\text{Eu}$. The existing data for the hyperfine structure in $^{151}\text{Eu}$ were reproduced with an exception for the level $z^0 P_{3/2}$.

1. Introduction

The transitions from the ground state $4f^7 6s^2 8S_{7/2}$ of europium I to the levels of the configuration $4f^7 6s 6p$ have been subject of many spectroscopic investigations. As early as 1935 Schüler and Schmidt [1] determined from the hyperfine structure (hfs) of some of the transitions the nuclear ground state spins of both stable isotopes 151 and 153 (natural abundances 47.8% and 52.2%) to be $I = 5/2$. The hfs of the ground state was studied with the atomic-beam-magnetic-resonance technique by Sandars et al. [2], resulting in precise values for the hfs constants.

The hfs of excited $4f^7 6s 6p$-levels has been measured e.g. by Müller et al. [3], Krüger et al. [4] and Kuhl [5] by means of interferometric methods and by Lange [6] and Champeau et al. [7] with the level crossing technique. Using the experimental data of Müller et al. [3], Bordarier et al. [8] analyzed the hfs of these levels with the effective operator formalism [9]. Lange [6] showed that the agreement between theory and experimental A(151)-factors could be improved by taking into account configuration interactions. He repeated Bordarier’s analysis with wavefunctions constructed by Smith et al. [10] from an analysis of fine structure data. Champeau et al. [7] showed this to be valid for the B(151)-factors as well.

Hitherto the hfs constants of $^{151}\text{Eu}$ of all levels but one ($z^0 P_{3/2}$) had been measured. For $^{153}\text{Eu}$ a considerably less complete picture was available, mainly due to the small hfs of this isotope. Isotope shifts (IS) have been measured by Brix [11], Krebs et al. [12], Müller et al. [3] and Heinecke et al. [13], but for some transitions data were still lacking. Moreover the existing data showed some discrepancies. In this paper results of a high resolution laser-atomic-beam experiment are given. All allowed transitions from the ground state in the wavelength region 435–630 nm were studied. From these experiments the hfs constants of the upper levels for both isotopes as well as the IS could be determined with an accuracy comparable with or better than earlier results.

2. Experiments

The light of a free running CW jetstream dye laser, pumped by an Ar+-laser (Spectra Physics model 580A, resp. model 171) was intersecting at right angles a well-collimated atomic beam of natural europium. The laser linewidth was 6–8 MHz when using the dye Rhodamine 6G (wavelength region 560–630 nm) whereas a linewidth of 10–12 MHz was obtained with the dye Stilbene 3 (wavelength region 435–470 nm). The laser was adjusted to the required wavelength with a Michelson type wavelength meter with an accuracy of 0.001 nm. The atomic
beam was produced by heating an oven to a temperature of about 1,000 K with electron bombardment. The collimation ratio of the atomic beam was 1:300, resulting in a residual Doppler width of less than 3 MHz.

The frequency of the laser was swept over the absorption profile of the transition and fluorescence light from the atomic beam was collected and focussed onto a photomultiplier. Photon counting techniques were used and great care was taken to reduce stray light from laser and oven. Laser scans were calibrated with either a 0.5 m or a 1 m long confocal Fabry-Pérot interferometer, the former having a thermal drift of less than 1 MHz per 20 min. The laser scans could be controlled by a PDP8 computer and the photon counting signal as well as the interferometer signal were then stored on magnetic tape. The interferometers were calibrated on the accurately known hfs of the $^2S_{1/2}$-sodium ground state and the $^2P_{3/2}$-indium metastable state. In the case of large hyperfine splittings or isotope shifts overlapping scans had to be made to cover the complete spectral line, since the laser scan was limited to 3 GHz. An interferometer with a free spectral range of 2 GHz was used to monitor this procedure. In this way the eight possible transitions in the wavelength region 435–630 nm were studied. Examples of completely recorded spectral lines are shown in Figs. 1–3.

The weak transition at 629.1 nm is shown in Fig. 1. This transition is near threshold of single mode Rhodamine 6G laser action and the detection efficiency of our photomultiplier (EMI 9789Q) was poor in this region. Nevertheless a good signal-to-noise ratio was obtained. The duration of a 3 GHz scan was typically about 2 min. Five overlapping scans had to be made to cover the complete structure. The linewidth of a single component was 8 MHz, dominated by the laser linewidth. The transitions in the blue spectral region are relatively strong. The linewidth of the hyperfine components is therefore mainly determined by the natural linewidth of about 30 MHz as is shown in Fig. 2 on the transition at 466.2 nm. The small hyperfine splitting of the ground state of $^{153}$Eu was not completely resolved in this case.

In Fig. 3 the transition at 576.5 nm is shown, where the hyperfine splitting is very small. The two structures belong to the isotopes $^{151}$Eu and $^{153}$Eu re-