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Radiative lifetime measurements on Pr atoms by observing time-resolved laser-induced fluorescence

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Abstract. Fourteen new lifetimes of Pr I low-lying states have been measured by using thermal atomic beam with single-step pulsed laser excitation and observing the decay of the fluorescence from the excited Pr atoms.

PACS. 32.70.-n Intensities and shapes of atomic spectral lines

1 Introduction

In the recent years, a lot of work has been done concerning the lifetime measurements in rare-earth elements, see a recent review [1]. While for similar research on praseodymium, a high melting point element with quite complicated electron configuration, only one reference [2] has been found, in which the lifetimes of 14 even-parity levels of Pr I have been measured using a multichannel delayed-coincidence method.

Most of the spectroscopic studies on Pr have concentrated on the hyperfine structure of Pr I energy levels and the designations of Pr I spectra [3–5]. For example, Childs and Goodman [3] measured 33 lines of Pr I transitions by using the technique of laser-radio frequency double-resonance in 1981, Reddy and Rao [5] investigated the Pr I and Pr II spectra in the range of 576.0−625.0 nm and obtained the information of the hyperfine structures of four spectral lines by using optogalvanic spectroscopy.

The interest in natural radiative lifetimes of excited states of rare earth elements is due primarily to their importance in astrophysical investigations, such as abundance determination of rare earth elements in the Sun and a class of peculiar stars; the origin of the sun and other stars; testing the theories of nucleosynthesis.

Our work is devoted to measuring the lifetimes of low-lying states in neutral Pr atoms, and 14 lifetime values were obtained by monitoring the time-resolved fluorescence from the studied excited states.

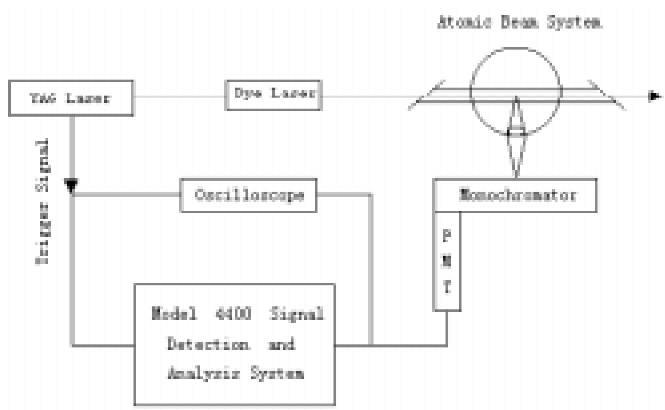

Fig. 1. Experimental set-up.

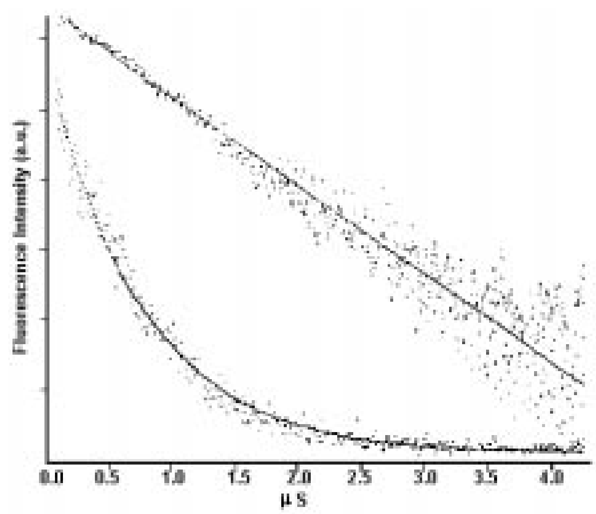

Fig. 2. The fluorescence decay curve of the Pr I energy level of 21398.47 cm^{-1}.

2 Experimental

The experimental set-up in this work is shown in Figure 1. A dye laser operated with the dyes of R610 and R590,

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Table 1. Natural radiative lifetime values of fourteen Pr I excited states measured in this work.

Excitation Wavelength (nm)	Configuration	J	Energy level (cm^{-1})	Parity	Lifetime (ns)
556.55[a]		17/2	28429.49	even	98(10)
579.22	$4f^3 6s6p$	9/2	18636.18	even	2469(276)
580.51	$4f^2 5d^2 6p$	11/2	25250.67	odd	4126(430)
581.14	$4f^2 5d6p$	11/2	27634.52	even	2042(255)
583.72	$4f^3 5d^2 6p$	11/2	22949.56	odd	4187(465)
585.01	$4f^3(^4I^0)6s6p$	13/2	21470.05	even	2100(230)
587.47	$4f^3(^4I^0)6s6p$	15/2	21398.47	even	756(82)
589.10	$4f^3 5d6p$	15/2	26654.48	even	3450(350)
590.70					2110(230)
591.98[b]		9/2	16887.84	even	3858(420)
593.39	$4f^3 5d6p$	11/2	35097.82	even	2957(310)
594.63	$4f^3 6s6p$	9/2	18189.22	even	1911(250)
595.48	$4f^2 5d^2 6p$	9/2	28501.82	odd	5102(510)
596.22	$4f^3 6s6p$	11/2	18144.32	even	2494(250)

[a] Reference [2]
[b] Reference [3]

pumped by a Nd:YAG laser (Molectron My-34) produced laser pulses with duration of 8 ns, linewidth of 0.01nm at a repetition rate of 10 Hz. The wavelength range of the tunable dye laser is 578−610 nm. In order to eliminate the influence from stray laser light on the experimental results, two long guide tubes with series collimation apertures and Brewster-windows were mounted in both the inlet and the outlet of the laser beam.

The atomic vapour of Pr was produced in an atomic beam apparatus which is composed of a high vacuum system, a molybdenum crucible containing praseodymium metal and an interaction chamber. An electron gun was used to impact the wall of the crucible as a heating source. The running temperature of the heating was kept at about 1200 °C by controlling the working voltage and current of the electron gun.

The produced atomic vapour formed an atomic beam through collimation by a series apertures, and entered the chamber perpendicularly to the laser beam.

The laser induced fluorescence was collected in the perpendicular direction to both laser beam and atomic beam and fed to a photomultiplier tube(PMT) *via* a monochromator. The signals produced by the PMT were introduced to the Model 4400 "Signal Detection and Analysis System" (EG&G PARC) to be processed *via* an amplifier. This system can record fluorescence decay curves by averaging a large number of individual signals, fit the experimental data to an exponential curve, and deduce the radiative lifetime values. An oscilloscope was used to monitor the signals when optimizing the resonant laser wavelength. The trigger signal of the measuring system came from the YAG laser.

3 Experimental results

Most of the states under study were populated from thermally populated lower levels, including odd and even parity, by laser excitation. Figure 2 shows a typical fluorescence decay curve, obtained with an excitation wavelength of 587.47 nm and a detection wavelength of 538.90 nm corresponding to a lifetime of 756 ns.

In general, by using single step laser excitation in the visible region and monitoring the decay fluorescence from the studied states, fourteen lifetimes were measured. Table 1 listed 14 lifetime values of Pr I measured in this work. Most of energy level locations are taken from NBS [6].

During the measurements the pressure in the vacuum chamber was changed and no effect on any of the measured lifetimes was observed.

For most measurements we kept pressure down to 1×10^{-4} Pa by adding a liquid nitrogen trap. In order to avoid *radiation trapping effect* on lifetime measurement, the atomic density was kept about 10^8 atoms/cm^3. Influences from *Zeeman quantum beats* can also be a problem. These measurements were performed in a sufficiently strong magnetic field to wash out any quantum beats.

At a temperature of 1200 °C, the mean velocity of the atoms is about 700 m/sec. For the longest lifetime given in Table 1 the $1/e$ decay length is nearly 3.5 mm. The field of view for the collecting fluorescence system is about 9 cm^2. Therefore the *flight out of view effect* could not be a big problem. The error bars given in Table 1 encompass the statistical scattering obtained from different runs, as well as an additional allowance of about 4% for possible systematic errors.

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