Investigation of the Autoionization Spectra of Samarium from 48800 cm^{-1} to 51200 cm^{-1}

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1 Introduction

The autoionization state is a quasi-bound state of an atom which lies above the ionization threshold of the outer valence electrons. This state plays a great role in the photoionization of atoms in plasmas and astrophysics. Hence, the investigation of the autoionization states has been of interest and a number of experimental and theoretical results have been reported recently.

The spectrum of the rare earth metal Sm is complex because of its partially filled $4f$ shell and the structures of the $[4f^6 6s^2]$ ^7F ground term. To our knowledge, there are only few results reported on the autoionization state of the Sm [1], [2]. In this paper, we report the autoionization spectra of atomic samarium(Sm) in the region from 48800 cm^{-1} - 51200 cm^{-1}, obtained from the three-step excitation. We measured the energy levels of the odd autoionization states.

2 Experiments and Results

Three-step excitation was used to investigate the autoionization state of Sm. The first excitation step was fixed at a transition from the ground state, $[4f^6 6s^2]$ $^7F_1$, to the first excited state $[4f^6 6s6p]$ $^7F_2^0$, the energy of which is 17190 cm^{-1}. Then the even states with the energies 34522 cm^{-1}, 34420 cm^{-1}, and 34399 cm^{-1} were chosen as the intermediate levels. Finally, the energies of the autoionization state were obtained by scanning the wavelengths of the ionization laser from 600 nm to 700 nm.

The experimental setup for three-step excitation is well described in Ref.[3]. The setup consists of a laser system, a time of flight mass spectrometer, and a detection system. For the first and the second excitation step, we used two single-mode dye lasers pumped by a frequency-doubled Nd:YAG laser. The transition to an autoionization state from the second excited state was made by using another broadband dye laser pumped by the same Nd:YAG laser. Two commercial wavemeters having resolutions of 200 MHz were used to measure the wavelengths of the two single-mode dye lasers. Additionally, to calibrate the ionization laser, a small portion of the dye laser beam was used to observe the optogalvanic spectrum of a Sm-Ar hollow-cathode discharge lamp. The frequencies of the single-mode pulse lasers were stabilized within 100 MHz during an experiment by a feedback system which consisted of two fabry-perot etalons and a piezoelectric transducer(PZT) attached to the oscillator of the laser. For step-wise excitation, the lasers were made to interact with the Sm atoms with a time delay of 10 ns, respectively.

The atomic beam of samarium was produced by a resistively heated tantalum boat containing the natural solid Sm up to a temperature of about 1000 K in a vacuum chamber. The generated Sm atomic beam was collimated by two slits and directed perpendicularly to the laser beam path

Table 1: List of the investigated autoionization states

Intermediate state(cm^{-1})	Ionizing Laser wavelength(nm)	Autoionization state(cm^{-1})	Fano q-parameter	Width (cm^{-1})	signal strength
34399 (J=1)	601.367	51022.9			m
	604.574	50934.8	32.7	23.7	s
	604.995	50923.3			w
	607.195	50863.4			m
	611.276	50753.5			w
	612.171	50729.5			w
	613.285	50699.9			w
	621.263	50490.6			w
	624.497	50407.3			w
	625.611	50378.8			w
	627.732	50324.8			w
	629.152	50288.9			m
	632.072	50215.5			w
	633.200	50187.3			w
	634.378	50158.0			w
	635.273	50135.8			w
	643.565	49932.9			w
	647.099	49848.1	52.9	5.1	s
	654.862	49664.9			w
	656.428	49628.5			w
	663.415	49468.1			m
	666.181	49405.6			m
	669.106	49340.0			m
	670.169	49338.5			m
	683.314	49029.3			m
	685.258	48987.8	48.6	5.0	s
	685.437	48984.0	56.2	6.4	s
	698.932	48702.4			w
34420 (J=2)	602.733	51007.0			m
	603.408	50988.5			w
	615.171	50671.6	41.1	6.0	s
	615.967	50650.9	64.6	7.8	s
	624.580	50426.8			w
	626.324	50382.3			w
	635.038	50163.2			w
	642.951	49947.8			w
34544 (J=3)	624.082	50541.3			w
	628.314	50433.4			m
	630.376	50381.4	109.5	8.1	s
	630.774	50371.3	22.4	6.0	s
	639.332	50159.2	-8.0	22.4	s
	652.319	49728.5	-87.8	9.1	s

in order to reduce the Doppler broadening to 30 MHz. The photo ions of Sm were detected at the end of the flight tube by a microchannel plate(MCP). Finally, the ion signals were averaged by a boxcar averager and the mass spectrum was recorded by a digitizing oscilloscope.

The experimental results showed a large number of autoionization lines in the region 48800 cm^{-1} - 51200 cm^{-1}. Neglecting the small lines, all experimental results are summarized in Table 1. In Table 1, s, m, and w represent strong, medium, and weak transition strengths, respectively.

By fitting the experimental data against Fano's formula [4], we obtained the resonance energy(E_r) and the linewidth(,) of the autoionizing states. Fano's formula is expressed as follows:

$$\sigma_{total}(\varepsilon) = \sigma_a \frac{(\varepsilon + q)^2}{\varepsilon^2 + 1} + \sigma_b$$

with $\varepsilon = (E\text{-}E_r)/(,\ /2)$, where σ_{total} represents the transition cross section, q is the Fano parameter, E is the incident photon energy, and σ_a and σ_b are the fitting parameters. Most q parameters recorded in Table 1 are much larger than 1 because the measured autoionization spectra exhibit nearly symmetric line profiles. In the energy range investigated in this work, we can observe ten relatively strong transition lines. Those lines can be used for efficient photoionization of Sm.

We presume that the measured autoionization lines are from $[4f^6 6s5d]$ configurations. However, to identify the measured lines, we need more experimental and theoretical efforts.

3 Summary

We investigated the autoionization spectra of atomic samarium by three-step excitation. In this study, we measured the energy levels of the odd autoionization states located in the region from 48800 cm^{-1} - 51200 cm^{-1}.

The first resonant step was fixed at a transition from the ground state, $[4f^6 6s^2]\ ^7F_1$, to the first excited state $[4f^6 6s6p]\ ^7F_2^0$, the energy of which is 17190 cm^{-1}. The even states with energies of 34522 cm^{-1}, 34420 cm^{-1}, and 34399 cm^{-1} were then chosen as the intermediate levels. Finally, the energies of the autoionization states were obtained by scanning the wavelengths of an ionization laser from 600 nm to 700 nm.

As a result of this work, forty-two autoionization states were found in the investigated range from 48800 cm^{-1} to 51200 cm^{-1}. Among the observed lines, Some lines are analysed by Fano's formula and q parameters are determined.

References

[1] V. E. Dobryshin, N. A. Karpov, S. A. Kotochigova, B. B. Krynetskii, V. A. Mishin, O. M. Stelmakh, and V. M. Shustryakov, *Opt. Spektrosk.* **54**, 415 (1983)

[2] Hu Sufen, MEI Shimin, ZHANG Sen, CHEN Xing, and XU Yunfei, *Chinese Phys. Lett.* Vol. **6**, No. 2 (1989)

[3] Hyunmin PARK, Hyun-chae KIM, Jong-hoon YI, Jae-Min HAN, and Jongmin LEE, *J. of Korean Physical Society.* Vol. **30**, 453 (1997)

[4] U. Fano, *Phys. Rev.* **124**, 1866 (1961)