Eur. Phys. J. A **1**, 3–5 (1998)

THE EUROPEAN
PHYSICAL JOURNAL A

Short note

Isotope shift and hyperfine structure measurements for ^{155}Yb by laser ion source technique

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Received: 2 October 1997 / Revised version: 24 October 1997

Abstract. The change in the mean square charge radius and electromagnetic moments of the neutron deficient ^{155}Yb isotope have been determined using resonance ionization spectroscopy in a laser ion source. The data point to an absence of a marked deformation change for Yb isotopes with N=84-86.

PACS. 29.25.Lg Ion sources: polarized

Recently a marked deviation [1] from the established systematic behaviour [2] of the isotopic dependencies of the charge radii was found for the Yb isotopes with N= 82-84. It was shown that the radii of these isotopes increase faster with the neutron number than the radii in the other isotopic chains in this region (see Fig. 1).

A satisfactory theoretical explanation for this effect has not been found yet. Thus it is of importance to continue the detailed experimental investigation of this region of the chart of nuclides. In particular, it is necessary to determine relevant nuclear characteristics for the adjacent odd Yb isotopes (A=153,155) and estimate the nuclear deformation for Yb isotopes, because it is the jump of deformation that could in principle causes the observed jump in nuclear radii.

To increase the sensitivity we apply the a resonance ionization spectroscopy in a laser ion source (RIS/LIS). This method is based on the multistep resonance photoionization of atoms of the isotope under investigation within the ion source. The first off-line investigation by the RIS/LIS method was performed for ^{221}Fr isotope [3]. The RIS/LIS method with advanced high-efficient LIS [4,5] developed at IRIS PNPI allowed to use it for studies of a large region of on-line produced nuclides. It was tested in the trial on-line experiment for ^{154,156}Yb [6]. It was shown that this method enables the observation isotopes at production rates less than 10^2 atoms per second.

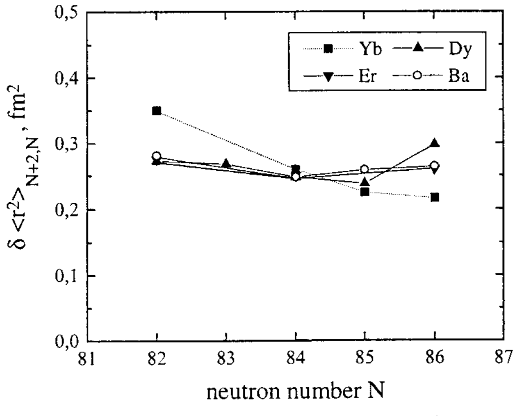

Fig. 1. Differential isotopic dependencies of $\delta\langle r^2\rangle_{N+2,N}$ for Ba (Z=56), Dy (Z=66), Er (Z=68) and Yb (Z=70)

In the present experiment the RIS/LIS method was applied for the investigation of ^{155}Yb. The following scheme of excitation of the Yb atoms was used: $6s^2\ ^1S_0 \longrightarrow 6s6p\ ^3P_1 \longrightarrow 4f^{13}(^2F_{7/2})6s^26p_{3/2} \longrightarrow$ continuum. The laser frequency of the first excitation step was scanned. The optical spectrum represents the number of photoions detected at the exit of the mass separator as a function of the scanned laser frequency. The scheme of the experimental set-up is presented in Fig.2.

Three Cu-vapour lasers (average power 9 W, repetition rate 9 kHz) were used to pump a narrow-band (linewidth 1 GHz) and two broad-band (30 GHz) dye lasers. The rays of the three lasers were merged in the niobium tube of the laser ion source (the diameter of the laser beam was 1 mm).

The average power of the narrow-band scanning dye laser was about 50 mW, the power of the broad-band dye lasers, tuned to the second transition frequency, was about 550 mW. Part of the scanning laser radiation was split from the main beam and directed to a Fabry-Perot interferometer (free spectral range 5 GHz) to provide frequency scale calibration. Another part of the laser beam was introduced into a reference chamber in order that a reference spectrum of the stable Yb isotopes could be simultaneously recorded. Atoms of ^{155}Yb were produced in the target of the mass separator by 1 GeV protons.

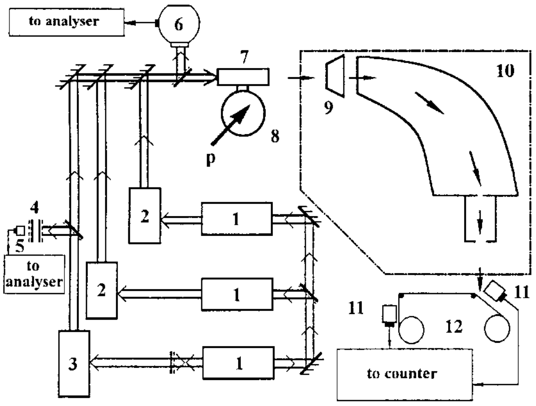

Fig. 2. Experimental set-up for investigation of the α- radioactive isotopes. 1 – Cu-vapour lasers; 2 – broad-band dye lasers; 3 – narrow-band scanning dye laser; 4 – Fabry-Perot interferometer; 5 – photodiode; 6 – reference chamber; 7 – laser ion source; 8 – target; 9 – extraction electrode; 10 – mass separator; 11 – α - detectors; 12 – tape-driving device; p – beam of protons

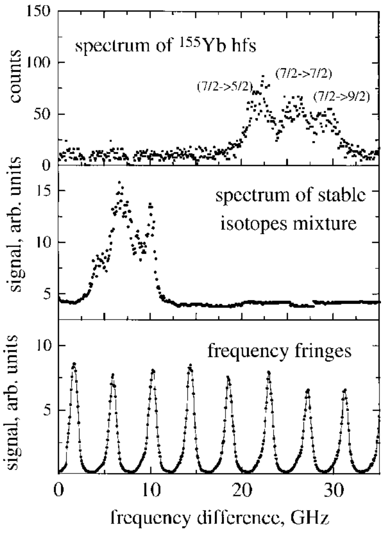

Fig. 3. Signals per one scan of the narrow-band laser

The target used was a new high temperature tantalum foil target inside a tungsten container developed for this experiment. Ytterbium atoms were ionized in the laser ion source and extracted by the extraction electrode of the mass separator. Photoions were detected at the mass separator exit by counting α-particles with the characteristic energy of the ^{155}Yb decay (E_α =5194 keV).

The optical spectra of stable and radioactive isotopes along with the interferometer transmission spectrum obtained during one scanning cycle of the narrow-band laser are shown in Fig. 3.

The values of the isotopic shift $\delta\nu_{155,168}$ and hyperfine structure constants A_{155}, B_{155} for the excited state of ^{155}Yb ($6s6p\,^3P_1$) have been extracted from the experimental spectra:

$$\delta\nu_{155,168} = -15460(80)\ MHz,$$

$$A_{155} = -1050(25)\ MHz,$$

$$B_{155} = 160(80)\ MHz$$

The magnetic dipole moment μ^{155} and electric quadrupole moment Q_s^{155} were evaluated with the aid of the scaling relations [7]:

$$\mu^{155} = -0.913(22)\ nm,\ Q_s^{155} = -0.5(3)\ b$$

Here we neglected the hfs anomaly, which does not usually exeed 1% [7].

Isotopic change of the charge radius $\delta\langle r^2\rangle_{A,A'}$ can be determine through the simple formula [7]:

$$\delta\nu_{A,168} = F\cdot\delta\langle r^2\rangle_{A,168} + M\cdot\frac{A-168}{A\cdot 168},$$

where F is the electronic factor and M is the mass shift constant. With F=11.9 GHz/fm^2 and M=296 GHz from [1] we obtain:

$$\delta\langle r^2\rangle_{155,168} = 1.316\ fm^2.$$

The error of this value is determined by the uncertainty in the semiempirical calculation of the F and M values. It is supposed to be about 5% [7]. In Fig.1 the isotopic changes of mean square charge radii for Yb isotopes with N=82-86 are presented. Corresponding data for Dy (Z=66), Er (Z=68) and Ba (Z=56) isotopes are also shown for comparison [7].

The smooth behaviour of the isotopic dependency of $\delta\langle r^2\rangle$ at ^{155}Yb points to the similarity of the structure of the adjacent Yb nuclei with A=154-156. In particular they must possess smooth deformation changes and no sudden jump in the course of $\delta\langle r^2\rangle$ is observed. We can estimate the corresponding change of the mean square deformation $\langle\beta^2\rangle$ by the two-parameter formula [7]:

$$\delta\langle r^2\rangle = \delta\langle r^2\rangle_0 + \frac{5}{4\pi}\langle r^2\rangle_0\cdot\delta\langle\beta^2\rangle,$$

where $\langle r^2\rangle_0$ and $\delta\langle r^2\rangle_0$ are the volume ms charge radius and differential radius calculated in the spherical droplet model. This estimation gives:

$$\delta\langle\beta^2\rangle_{154,155} < 0.001.$$

The data from the quadrupole moment of ^{155}Yb infer a negligibly small deformation. This infers that ^{154}Yb has also only rather small (if any) intrinsic deformation. Therefore one can not explain the anomalous behaviour of the charge radius of ^{154}Yb by the marked deformation jump at ^{154}Yb. This effect appears to have a more complex nature and to understand it additional information is needed.

We would like to express gratitude to T.T. Fedorov, A.G. Poljakov, D.M. Seliverstov and V.N. Fedoseev (IS RAS, Moscow) for helpful assistance.

The work was partly supported by Russian Foundation for Basic Research (RFBR), grants *NN* 96-02-17996, 95-02-03674-a.

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