EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/87-204
10.11.1987

NUCLEAR GROUND STATE PROPERTIES OF STRONTIUM ISOTOPES ($78 \leqslant A \leqslant 100$) BY LASER SPECTROSCOPY

(IS83)

F. Buchinger, E.B. Ramsay
McGill University/FRL, Montréal, Canada H3A 2B2

R.E. Silverans, P. Lievens
Katholieke Universiteit, Leuven, Belgium

E. Arnold, W. Neu, R. Neugart, K. Wendt
Universität Mainz, Mainz, FRG

D. Berdichevsky, R. Fleming, D.W.L. Sprung
McMaster University, Hamilton, Canada L8S 4M1

G. Ulm*), the ISOLDE Collaboration
CERN, Geneva, Switzerland

ABSTRACT

We report on the measurements of nuclear ground state spins, moments and changes in mean square charge radii in a series of Strontium isotopes between A=78 and A=100 by collinear fast-beam laser spectroscopy. The experiment was carried out on-line at the ISOLDE mass separator at CERN using the traditional photon counting as well as a new particle detection method of fast beam spectroscopy. The results are presented and discussed in the light of the rapid change of nuclear shape within the investigated isotopic series.

INTRODUCTION

The series of Strontium (Sr) isotopes reaches from the valley of stability (at N=50) with isotopes showing spherical shape to strongly deformed isotopes on both sides of the stability line. Since the variation of the nuclear shape happens over a remarkably short interval of approximately 20 neutrons, this even Z element has found considerable interest from the experimental, as well as from the theoretical physics side. The predicted strong ground state deformation at $N \approx 40$ and $N \approx 60$[1] has been established through measurements of BE2 values[2]. Laser spectroscopy experiments of the ground state spins, moments and charge radii mainly cover the transitional region of the neutron deficient isotopes[3,4]. We have extended those studies to Sr isotopes in the mass region $78 \leq A \leq 100$. This coherent information on nuclear ground state properties at both sides of the neutron shell closure, allows a systematic study of the development of the strong deformations under various aspects.

Contribution to the "5th International Conference on
Nuclei far from Stability", September 1987,
Rosseau Lake, Ontario, Canada

---

*) Present address: PTB, D-1000 Berlin 1

EXPERIMENT

Nuclear spins (I), magnetic moments (μ_I) and spectroscopic quadrupole moments (Q_s) were obtained from optical hyperfine structure (hfs) measurements in the 5s $^2S_{1/2}$ - 5p $^2P_{3/2}$ transition (λ = 407.8 nm) of the Sr ion. Information about changes in mean square charge radii ($\delta<r^2>$) were derived from the isotopic shifts (IS) in the same line. The experiment was carried out on-line at the ISOLDE mass separator at CERN. We used the technique of collinear fast-beam laser spectroscopy and an experimental procedure similar to that one described in Ref. 5 for the measurements of the isotopes between A=78 and A=98. The measurements were extended to ^{100}Sr by the first on-line application of a new variant of collinear fast-beam laser spectroscopy proposed and developed by Silverans et al.[6]. A detailed description of the apparatus and its application in the Sr measurements is given in Ref. 7 and we restrict ourselves to a schematic description of the technique. In an optical pumping region the Sr ions in the fast beam interact in collinear geometry with the laser light. When the frequency tuned laser light is resonant with the Doppler shifted 5s-5p transition, multiple excitation at resonance leads to a strong depopulation of the ground state and correspondingly to a high occupation of the low-lying 4d metastable states. The ion beam is then sent through a Na-vapour charge transfer cell. Since the neutralization cross-section (σ) for Sr ions in Na is state dependent (e.g. $\sigma(4d)/\sigma(5s)$ = 1.5 at 60 keV ion energy), the optical pumping process at resonance can be conveniently detected by particle counting. For this purpose the ions are subsequently separated from the neutral particles by an electrostatic deflector and the atoms are counted via secondary electron emission after impact on an aluminum tape. Frequency calibration of the laser scan in the ^{100}Sr measurements was achieved by recording the signal of a reference isotope (e.g. ^{94}Sr) by optical detection at two different ion energies and unchanged laser settings.

RESULTS and DISCUSSIONS

The magnetic moments and spectroscopic quadrupole moments of the odd A isotopes and isomers in the investigated Sr series are shown in Tab. I. For the calculation of μ_I and Q_s from the ratio of the hfs constants of the respective isotopes, we have used μ_I = 1.093602 (1) nm[8] and Q_s= 0.335 (20) b[9] for ^{87}Sr, where Q_s is corrected for Sternheimer type polarization effects. In Tab. I we have also listed the nuclear ground state spins of the respective isotopes. Our spin measurements confirm the most recent assignments from nuclear spectroscopy studies[8,10,11] except for ^{93}Sr (I=5/2) and ^{97}Sr (I=1/2). For this isotope, which is situated on the borderline between spherical and strongly deformed nuclear shape in the narrow range of neutron numbers where shape coexistence is indicated[1,12], a spin assignement of I=3/2 was recently suggested by several authors[12,13]. Our results characterize the ^{97}Sr ground state as a $s_{1/2}$ shell model state, a conclusion also supported by the nearly identical magnetic moments of ^{95}Sr and ^{97}Sr (see Tab. I).

A	I	μ_I (nm)		Q_s (b)	
79	3/2	-0.474	(2)	0.744	(54)
81	1/2	0.5440	(4)		
83	7/2	-0.830	(2)	0.766	(58)
83^m	1/2	0.582	(1)		
85	9/2	-1.0011	(9)	0.283	(22)
85^m	1/2	0.6008	(4)		
87	9/2	-1.093602	(1)	0.335	(20)
87^m	1/2	0.6282	(6)		
89	5/2	-1.1488	(7)	-0.274	(19)
91	5/2	-0.8868	(6)	0.044	(5)
93	5/2	-0.7942	(5)	0.265	(19)
95	1/2	-0.5379	(4)		
97	1/2	-0.500	(1)		

Table I: Spins (I), magnetic moments (μ_I) and spectroscopic quadrupole moments (Q_s) in the investigated Sr series.

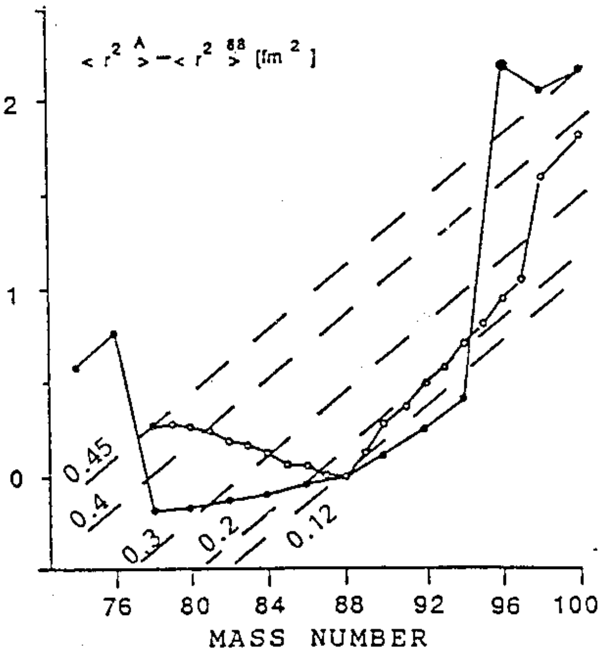

Fig. 1: Changes of mean square charge radii of Sr isotopes (open circles). The predictions from the droplet model for deformations $\langle\beta\rangle^{1/2}$ ranging between 0.12 and 0.45 are shown as broken lines. HF+BCS results (force SKa) are given as full dots.

Changes of mean square charge radii were obtained from the optical data following the standard procedure of Heilig and Steudel^{14}. We use a calibratration factor (notation as in Ref. 14) of F=1579(47) MHz/fm^2 and a specific mass shift (SMS) of SMS=-0.19(15) NMS with NMS being the normal mass shift in the Sr-D2 transition. The resulting $\delta\langle r^2\rangle$ values are plotted relative to ^{88}Sr as reference isotope in Fig. 1. Similar to the Sr neighbour Rb^{15}, a decrease in $\langle r^2\rangle$ is observed for the neutron deficient isotopes when N is increased. For the neutron rich isotopes a steep increase of $\langle r^2\rangle$ between N=59 and N=60 is found after a more regular variation for the isotopes between the closed neutron shell at N=50 (^{88}Sr) and N=59, respectively.

The experimental values can be interpreted in terms of changes in ground state deformation, by comparing them to the predictions from the droplet model^{16}. The droplet-isodeformation curves calculated with the model parameter set of Ref. 17 for deformations between $\beta = 0.12$ and $\beta = 0.45$ are included in Fig. 1. The predicted sudden onset of deformation on both sides of the line of stability^1 is observed only for the neutron rich isotopes, whereas on the neutron deficient side the deformation develops more smoothly. The deformations deduced for the strongly deformed isotopes at the extrema of the investigated isotopic series agree with those derived from BE2 values (see Tab. 2). An indication for static prolate deformation of the lightest isotopes comes from the intrinsic quadrupole moment of ^{79}Sr, Q_0=+3.72 (27) b, derived from Q_s under the assumption of strong coupling. The Q_0 of ^{79}Sr is similar in magnitude to that one of its even neighbour ^{78}Sr, where Q_0=3.28 (21) b is found from its BE2 value.

Table II. Deformation parameters derived from BE2 values[2]

A	78	80	82	84	86	88	98	100
$<\beta^2>^{1/2}$	0.43(3)	0.38(2)	0.29(1)	0.21(2)	0.13(1)	0.117(3)	0.36(2)	0.37(1)

For the neutron deficient transitional isotopes the puzzeling discrepancy between deformations obtained from the IS in the frame of the droplet model and from BE2 values, already discussed for the stable isotopes[18], persists towards lower neutron number.

For a more thorough interpretation of the trend of Sr charge radii, we have extended our calculations of mean square charge radii in the HF+BCS approach[18] to isotopes between A=74 and A=100. The results are included in Fig. 1. Similar to the findings of other authors[19], an abrupt onset of static ground state deformation is predicted for the heavy as well as for the light Sr isotopes. A detailed discussion of these calculations will be presented in a forth-coming more extended presentation of the results.

1. J.H. Hamilton et al., Rep. Prog. Phys. **48**, 631 (1985) and references therein.
2. S. Raman et al., At. Data Nucl. Data Tables **36**, 1 (1987) and references therein.
3. D.A. Eastham et al., Daresbury Lab. Preprint DL/NUC/P243E.
4. M. Anselment et al., Z. Phys. **D3**, 421 (1986).
5. K. Wendt et al., Z. Phys. **A318**, 125 (1984).
6. R.E. Silverans et al., Nucl. Instr. Meth., **B26**, 591 (1987).
7. R.E. Silverans et al., to be published.
8. Table of Isotopes, ed. by C.M. Lederer and V.S. Shirley (Wiley, N.Y. 1978).
9. S.M. Heider et al., Phys. Rev. **A16**, 1371 (1977).
10. B. Pfeiffer et al., Proc. 4th Int. Conf. on Nuclei Far From Stability, CERN 81-09, 423 (1981).
11. C.J. Lister et al., Phys. Rev. Lett. **49**, 308 (1982).
12. R.A. Meyer, Hyp. Int. **22**, 385 (1985) and references therein.
13. K.L. Kratz et al., in: Nuclei off the Line of Stability, 190th Nat'l. Meeting Am. Chem. Soc., Chicago (1985), Eds. R.A. Meyer and D.S. Brenner, ACS Symp. Series **324**, 159 (1986).
14. K. Heilig et al., At. Data Nucl. Data Tables **14**, 613 (1974).
15. C. Thibault et al., Nucl. Phys. **A367**, 1 (1981).
16. W.D. Meyers et al., Nucl. Phys. **A410**, 61 (1983).
17. D. Berdichevsky et al., Z. Phys. **A322**, 14 (1985).
18. F. Buchinger et al., Phys. Rev. **C32**, 2058 (1985).
19. P. Bonche et al., Nucl. Phys. **A443**, 39 (1985) and references therein.