Differences in the isotopic changes in the charge radii of nuclei with $50 \leqslant (N, Z) \leqslant 82$

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The isotopic shifts and hyperfine splitting of optical lines have been measured for europium, samarium, and neodymium isotopes with $N < 82$ neutrons at a laser installation at the IRIS mass-separator of the Leningrad Institute of Nuclear Physics. The isotopic behavior of the charge radii of the nuclei is found to depend critically on the proton number.

Study of the ground states of nuclei by laser techniques is a rapidly developing field of nuclear physics. By measuring the isotopic shifts and hyperfine splitting of optical lines one can obtain information on the isotopic changes in the mean square charge radii, spins, magnetic dipole moments, and electric quadrupole moments of the nuclei. Various laser techniques have revealed many effects, which have yet to receive an exhaustive theoretical explanation.[1] We might include in this group of new and unexpected effects the sharp Z dependence of the isotopic behavior of the charge radii, whose observation is being reported here.

The measurements were carried out at a laser installation which has been constructed at the IRIS mass separator of the Leningrad Institute of Nuclear Physics, Academy of Sciences of the USSR, in collaboration with the Institute of Spectroscopy, Academy of Sciences of the USSR. The isotopic shifts and hyperfine splitting were measured for the transitions with the wavelengths 588.8 nm in neodymium, 600.4 nm in samarium, and 576.5 nm in europium. For the isotopes $^{141-151}$Eu, we had measured the isotopic shifts previously. In the present study we have supplemented these results with measurements of the isotopic shifts for $^{138-140}$Eu. The parameter values required for determining the changes in the mean square radii, $\Delta\langle r^2\rangle_{A,A'} = \langle r^2\rangle_{A'} - \langle r^2\rangle_A$, for two isotopies with atomic numbers A and A' in Nd and Sm were found by the standard procedure of King's curves.[4] We used data on the isotopic shifts for the stable isotopes of these elements for other optical transitions.[5,6] The procedure for calculating $\Delta\langle r^2\rangle$ for Eu is described in detail in Refs. 2 and 3.

Figure 1 shows the results of measurements of $\Delta\langle r^2\rangle$ for the Sm and Nd nuclei. The data of Refs. 5–7 were used for the stable and long-lived isotopes of these elements. The anomalously large values of $\Delta\langle r^2\rangle$ found for ^{145}Sm in Ref. 8 is not confirmed by our experiments. In Fig. 1 we can clearly see a shell effect, manifested as different rates of change of $\Delta\langle r^2\rangle$ on the two sides of the magic number $N = 82$. A similar effect has been observed previously for isotopes of baryon, cesium,[1] and europium.[3] However, while the curves of the isotopic dependence of the mean square

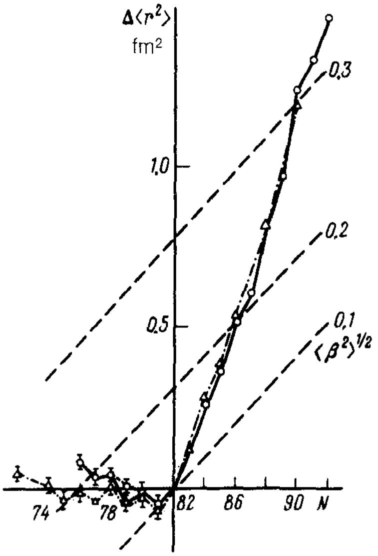

FIG. 1. Isotopic dependence of the mean square charge radius. ○—For Sm nuclei; △—Nd nuclei.

charge radius are essentially equal to each other for all these elements in the interval $82 < N < 88$ (see Ref. 1 and also Fig. 1 of the present paper), at $N < 82$, we see a strong Z dependence in the nature of the change in the mean square charge radius as a function of N (Fig. 2): The charge radii of the nuclei $_{54}$Xe, $_{55}$Cs, and $_{56}$Ba fall off

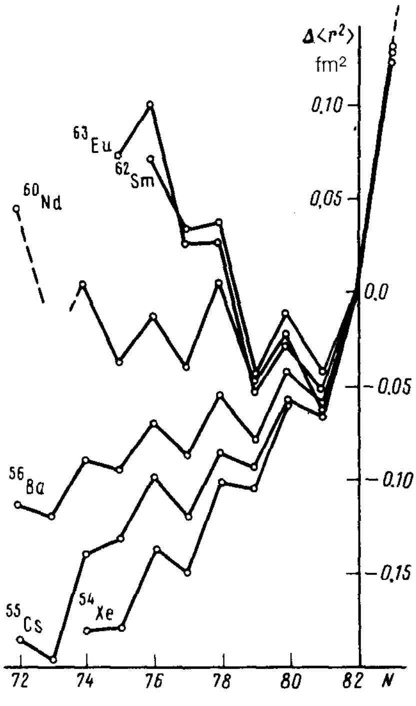

FIG. 2. Isotopic dependence of the mean square charge radius at $N < 82$ for the nuclei $_{63}$Eu, $_{62}$Sm, $_{60}$Nd, $_{56}$Ba, $_{55}$Cs, and $_{54}$Xe.

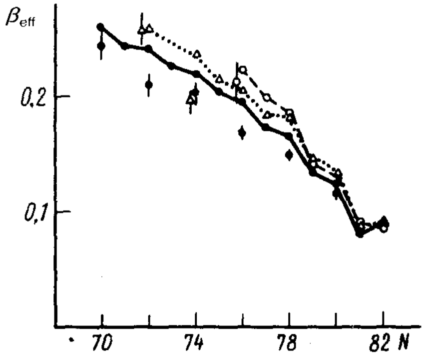

FIG. 3. Effective deformation for several nuclei: ●—$_{62}$Sm; Δ—$_{60}$Nd; O—$_{56}$Ba [see expression (1)]. The points with the error bars show values of β_{eff} found for even-even nuclei from data on $B(E2)$.

slowly with decreasing[1] N; in the case of $_{60}$Nd, and radii remain essentially constant as N varies from 82 to 74; and for the nuclei $_{62}$Sm and $_{63}$Eu they increase at $N<78$.

The strong Z dependence observed for the rate of change of the mean square charge radius as N is varied appears to stem from differences in the rate of change of the deformation of the corresponding nuclei. Let us estimate the effective deformation of these particular nuclei. The changes in the mean square charge radius of the nuclei can be described by the sum[1]

$$\Delta\langle r^2\rangle = \Delta\langle r^2\rangle_0 + \frac{5}{4\pi}\langle r^2\rangle_0 \Delta\langle\beta^2\rangle, \tag{1}$$

where $\Delta\langle r^2\rangle_0$ is the change in the mean square charge radius of spherical nuclei whose volume is the same as that of the nuclei under consideration, and $\Delta\langle\beta^2\rangle$ is the change in the mean square values of the deformation of these nuclei. Using (1), we find the effective deformation $\beta_{eff} = \langle\beta^2\rangle^{1/2}$ from the experimental values of $\Delta\langle r^2\rangle$ and the values of $\Delta\langle r^2\rangle_0$ calculated from the Myers-Swiatecki liquid-drop model.[9] The values of the effective deformation for the magic nuclei, with respect to which the values of $\Delta\langle r^2\rangle$ are measured, are found from the known values[10] of $B(E2,2_1^+ \to 0^+)$.

Figure 3 shows values of β_{eff} found with the help of expression (1) for Sm, Nd, and Ba nuclei. Shown in the same figure are values of β_{eff} calculated from the experimental values of $B(E2)$ for some of these nuclei.[10] It can be seen from Fig. 3 that these values of β_{eff} agree with the values from $\Delta\langle r^2\rangle$, confirming the validity of evaluating β_{eff} from (1). The nature of the isotopic dependence of β_{eff} at $N\leqslant 78$ is for the most part reproduced in the macroscopic-microscopic approach.[11] Since calculations of this sort consider only the static deformation, this correspondence between theory and experiments seems to show a strong static deformation of nuclei with $N<78$. This conclusion is confirmed by our measurements of the quadrupole moment of $^{135}_{60}$Nd$_{75}$. Using the standard formulas and the measured quadrupole moment $Q_s = 2.05(41)$ b, we can estimate the static deformation parameter of this nucleus: $\beta_{st} = 0.20(5)$. This estimate agrees with an estimate of β_{eff} found for ^{135}Nd from expression (1).

It is important to note that $\Delta\langle r^2\rangle$ is highly sensitive to slight relative changes in the deformation of the nuclei, so that it is possible to establish the difference in the nature of these changes at $N < 82$ and $N > 82$ (the presence or absence of a Z dependence).

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