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PROPOSAL TO THE PSC COMMITTEE

NUCLEAR GROUND STATE PROPERTIES IN STRONTIUM BY FAST BEAM LASER SPECTROSCOPY

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SUMMARY

Optical experiments have contributed to a detailed mapping of nuclear ground state properties over extended regions of the nuclear chart and provided data for the improvement of the descriptive and predictive power of nuclear models.

Up to now, one particulary interesting region has found little attention from the optical spectroscopy groups, namely the region near Z = 40. Here, the influence of the N = 50 shell closure, of the Z, N = 40 quasi-shell closure and of the strong deformations near Z, N = 38 and Z = 40, N = 60 on nuclear ground state properties can be studied over a remarkably short interval of N.

We therefore propose to measure the nuclear spins, moments and changes in mean square charge radii in strontium using the method of fast beam laser spectroscopy.

The experiment in the even-Z element strontium will provide complementary information to the rubidium data available for $76 \leq A \leq 98$. For the first time, it will allow a direct comparison of nuclear ground state properties in the Z = 40 region with mean field theories.

1. SCIENTIFIC MOTIVATION

The comparison of experimentally determined nuclear ground state properties (such as masses, spins, moments and changes in mean square charge radii) with theoretical calculations allows to improve nuclear models in their descriptive capabilities and - more important - in their predictive capacity. In particular the comparison with systematic data over long isotopic, isotonic and isobaric sequences represents a stringent test of the validity of a nuclear model.

Optical experiments have contributed during the last semi-decade to a detailed mapping of nuclear ground state properties over extended regions of the nuclear chart. One particular region, however, has found little attention so far from the optical spectroscopy groups, namely the region near $Z = 40$.

Here, as the only systematic optical experiment, hyperfine structures and isotope shifts in Rb ($Z = 37$, $76 \leq A \leq 98$) were measured /KBN 79, TTB 81/.

The optical data - also available for the stable and some long-lived radioactive isotopes in Kr, Sr, Zr and Mo - in connection with information from nuclear spectroscopy experiments reveals a rich manifold of physics phenomena.

The influence of the $N = 50$ shell closure on nuclear charge distributions can be studied with help of the stable and long-lived isotopes of the elements with $Z \approx 40$, $N \approx 50$. The data reveals the striking feature of decreasing mean square charge radii with increasing neutron number (for Kr, Rb and Sr) below the shell closure and rapidly increasing charge radii (for Rb, Sr, Zr and Mo) for the neutron rich isotopes (for references see /BCR 85/).

Nuclear spectroscopy experiments /HHZ 84/ and mass measurements /EAT 79/ have confirmed the theoretically predicted regions of large deformation ($\varepsilon_2 \approx 0.35$) near $Z \approx 38$, $N \approx 38$ and $Z \approx 38$, $N \approx 60$ /MNi 81/. The onset of this deformation can also be followed in the optical Rb data when the changes in mean square charge radii are interpreted in the traditional model of a smooth volume dependence for a spheroid of variable deformation /UOt 75/. In this picture a sudden onset of deformation is observed near N = 60 whereas the change in nuclear shape towards the neutron deficient side develops more gradually.

Rapid shape transitions in the isotopes with N ≈ 38 - 40 and N ≈ 60 as the result of the competitive influence of the proton and neutron configurations on the nuclear shape, can also be expected in the Rb neighbours on the ground of the distinct gaps in the single particle spectrum for neutrons and protons, at (N,ε_2) or $(Z,\varepsilon_2) \approx (40,0)$, $(38,+0.4)$, $(36,-0.4)$ and $(34,-0.3)$ (see Fig. 3.18 in ref. /HHZ 84/). Moreover, several calculations of deformation energy surfaces /HHZ 84, BFH 85/ indicate the presence of shape isomerism near those neutron numbers.

In order to study in more detail the influence of neutron and proton configurations in the Z = 40 region on nuclear ground state properties we propose to extend the measurements of hyperfine structures and isotope shifts to other elements in this region, in particular to Sr, where we have already carried out measurements near the line of stability /BCR 85/.

Level structure studies and measurements of B(E2) values in ^{78,80,98,100}Sr reveal large ground state deformations ($\varepsilon_2 \approx 0.35$) near N = 40 and N = 60 /LVO 82, SPM 80, ABC 79/. This deformation is predicted also from calculations of the quadrupole moments by Möller and Nix /MNi 81/. Similar to the case of Rb a sudden onset of permanent deformation is indicated at those neutron numbers.

For the heavy Sr isotopes this strong static deformation is also given by Hartree-Fock calculations /CEp 80/, and well documented by the level structure of ^{98}Sr and ^{100}Sr the E_{4^+}/E_{2^+} ratios being close to 3.3, the value of a pure rotator.

The situation is more controversal for the neutron deficient isotopes. Near-spherical shape is predicted for all isotopes below the N = 50 shell closure by the mean field theory and thus the strong deformations observed in ^{78}Sr and ^{80}Sr have to be attributed - in contrast to the predictions of Möller and Nix - to dynamic effects not included in the Hartree-Fock approaches. The presence of zero point quadrupole vibrations is observed in Rb for $46 \leq N \leq 49$ /APP 73/, and also in the case of ^{82}Sr (N = 44) the E_{4^+}/E_{2^+} ratio indicates pure vibrational character ($E_{4^+}/E_{2^+} = 2$). In ^{80}Sr (N = 42) and ^{78}Sr (N = 40) the observed strong enhancement of the E2 transition strength together with the level spacing favours a rotational behaviour. However, the ratios of the E_{4^+}/E_{2^+} energies are 2.5 and 2.8, respectively, for those isotopes and thus still far away from the value of a rigid rotor. The increase of the moments of inertia with spin furthermore indicates that a common, rigid shape is only approached for higher spins /LVO 82/.

Concerning the character of deformation we expect additional information from the measurements of the spectroscopic quadrupole moments in an optical experiment on Sr.

Due to its even proton number Sr is an attractive candidate for theoretical work in the frame of mean field theories. The description of the systematics in mean square charge radii, influenced by the N = 50 shell closure, the Z = N = 40 quasi-shell closure and the presence of strong deformations of possibly different character to both sides of the neutron shell closure, will be a stringent testing ground for specific Hartree-Fock forces.

Here, the theoretical work of Campi and Epherre /CEp 80/ using the effective force SKYRME VI was already mentioned above. Bonche et al. use the force SKYRME III for an investigation of the triaxial stability of the deformed ground states in the deformation regions $N \approx 38$ and $N \approx 60$ /BFH 85/. The results indicate shape isomerism near ^{100}Sr and the onset of strong static deformation at N = 60 and N = 38. Our group has carried out calculations on Sr near the stability line with force SKa as well as with the finite range force GOP with special emphasis on the investigation of the connection between changes in mean square charge radii and changes in nuclear surface thickness /BCR 85/. We are currently working on an extension of those calculation towards the isotopes far off stability.

The measurements in Sr will allow for the first time to compare these predictions for doubly-even isotopes directly with extensive experimental nuclear ground state data in the Z = 40 region.

Last but not least it should be mentioned that the combined analysis of changes in mean square charge radii with B(E2) values available for Sr isotopes far off stability and the Hartree-Fock calculations will also be useful in order to put more light on the utility of the traditional interpretation of changes in mean square charge radii where all shell effects are ascribed to (dynamic or static) deformation /UOt 75/. Measurements in Kr /GMR 79/ and Sr /BCR 85/ near the N = 50 shell closure suggest an extension of the model by a term describing changes in the surface thickness of the nuclear charge distribution. Through a more systematic study of changes in mean square charge radii in Sr we expect to gain more information on the validity of this approach.

2. EXPERIMENTAL DETAILS

The measurements in Sr will be carried out using the fast beam laser spectroscopy set-up of the Mainz group at ISOLDE II. Photon counting will be implied for the detection of the optical transitions. For the excitation of the Sr isotopes by cw-laser light, three ground state transitions in the visible are accessible. the Sr I $5s^2\ ^1S_0 - 5s5p\ ^1P_1$ transition ($\lambda = 460$ nm), because of the small hyperfine splitting, is useful only for the even isotopes. For measurement of all isotope shifts and the hyperfine structures of the odd isotopes the Sr II $5s\ ^2S_{1/2} - 5p\ ^2P_{1/2,3/2}$ transitions ($\lambda = 421$ nm and $\lambda = 408$ nm, respectively) will be used.

The excitation scheme in Sr is similar to that one in Ba and Ra, both of which were investigated earlier by the fast beam method. In analogy to these cases, we expect the sensitivity limit of the method to be in the oder of $10^4 - 10^5$ ions sec^{-1} delivered in the mass-separated ISOLDE beam.

Extensive information on the Sr yields at ISOLDE II is not available and for an estimate on the number of isotopes which can be covered by the measurements we have to rely on the Rb yields communicated /Rav 84/ as well as on the only Sr intensity given in the same reference (^{100}Sr: 10^3 ions sec^{-1}). Supposing a decrease in beam intensity of a factor of 10 per mass number for the isotopes far off stability, we expect to reach ^{98}Sr on the neutron-rich side. For the neutron-deficient side we expect to reach at least the lightest known isotope ^{77}Sr.

Developments are going on to improve the sensitivity by ion-counting detection, using the state-selectivity of charge transfer in combination with optical pumping from the 5s ground state to the 4d metastable states /SBD 85/. This may lead to a continuation of the experiment in the future.

3. ISOLDE REQUIREMENTS

General: Same as for experiment IS 80

Targets: Uranium carbide: W-surface ionization for the neutron-rich isotopes
Niobium powder: W-surface ionization for the neutron-deficient isotopes

Beam time: 18 shifts in 2 runs with both targets available. One target change (not included in the time request) should be scheduled for each run. If the time has to be divided into 4 runs with one target each, we need 2 shifts per additional run, i.e. 22 shifts. For testing purposes 2 shifts of stable Sr beam before the first run is desireable.

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