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High spin states of ^{84}Sr

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High spin states of ^{84}Sr nucleus excited through the ^{52}Cr(^{36}S,2p2n) reaction at 130 MeV energy were studied utilizing the Oak Ridge Compton-Suppression Spectrometer System. The level scheme has been extended up to probably $I^{\pi}=(24^{+})$ at 15 084 keV excitation energy for the positive parity band. The moment of inertia, for angular frequency higher than 0.58 MeV, presented an almost constant value.

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The recent advent of very sophisticated instrumentation for gamma-ray spectroscopy studies, as is the array of Compton-suppressed detectors, stimulate even more the interest in the research of the mass 80–90 region. Previous studies, up to about the angular momentum of 14$\hbar$, establish different phenomena such as the change in moment of inertia with spin, the rapid variation of nuclear properties as a function of particle number, and other effects described in an expression like the "softness" or "transitional" nuclear characteristic. The new instrumentation greatly expanded the angular frequency region in which this interesting phenomena could be investigated. An example is the recent study of ^{82}Sr [1] which determined a rich variety of different shapes evolving with spin and coexisting in the same nuclei. Continuing with this effort we report the study of ^{84}Sr at high angular momentum.

The Sr isotopes which have a "semimagic" proton number Z=38 and, in particular, ^{84}Sr, which is only four neutrons away from the N=50 closed shell, present a nuclear structure characteristic of a "spherical" nucleus. Therefore the study of this nucleus could provide important information over the shell gaps and their evolution as a function of angular momentum. The ^{84}Sr nucleus was populated with the fusion-evaporation reaction ^{52}Cr(^{36}S, 2p2n) by use of a 130 MeV ^{36}S beam from the HHIRF facility at Oak Ridge National Laboratory (ORNL). The target was a stack of two self-supporting 275 μg/cm^2 thick foils enriched in ^{52}Cr. The experimental setup consisted of the ORNL Compton-Suppression Spectrometer System with 18 Ge detectors and 52 elements of the Spin Spectrometer [2] which measured the γ rays multiplicity. The resulting γ-γ coincidence matrix was constructed according to the requirement that the signals from at least 12 NaI detectors should be present in each event. Previous works of Dewald *et al.* [3] used the reaction ^{76}Ge(^{12}C, 4n) to populated states up to 6740 and 6070 keV energy, which are deexcited by the 1086 and 625 keV γ rays, respectively. They reported a maximum angular momentum of 14$\hbar$. Figure 1 shows some of the results of the present coincidence experiment and, in particular, the sum of the already known 1086 and 1119 keV γ-ray transitions which deexcite positive parity states. The analysis of the sum of the 1267 and 1420 keV, which are in coincidence with the previous sum gate, and the total sum of both sum gates shown in Fig. 1 gives evidence to establish four new γ-ray transitions, namely, 1267, 1420, 1635, and 1862 keV and tentatively one with 2160 keV energy. This new cascade presents a regular increase in γ-ray transition energy with level energy together with the absence of crossover transitions, which suggest a quadrupole multipolarity for the γ rays.

On the other hand, analyzing the coincidence spectra gated by the negative parity γ-ray transitions as 808, 1148, and 719 keV results that three more γ rays are added to the decay scheme. The order in the decay scheme, for the 415 and 432 keV γ rays, shown in Fig. 2 is uncertain. Besides, most of the γ-ray intensity shown in Fig. 2 was obtained analyzing the different gates due to the particular complexity of the singles γ-ray spectrum. Concluding, the analysis of the present result allows one to extend the maximum angular momentum of the populated states up to tentatively $I^{\pi}=(24^{+})$. Here we discuss briefly the nuclear structure of ^{84}Sr. The positive parity excitation at low angular momentum shows an almost constant γ-ray transition energy with spin, which is characteristic of a spherical nucleus. At about 3.5 MeV this energy pattern is interrupted with two 8^{+} states whose lifetime measurement [4] characterizes them as the bandhead of two-quasiparticle bands. In particular there is strong evidence [4] that the 8^{+} states at 3.68 MeV energy is a two-proton alignment band. Towards higher energies a shell-model approach in which aligned pairs of particles moving on an spherical $g_{9/2}$ shell could account for the measured spectrum. Weiszflog *et al.* [5] apply this approach to describe successfully the nuclear structure of

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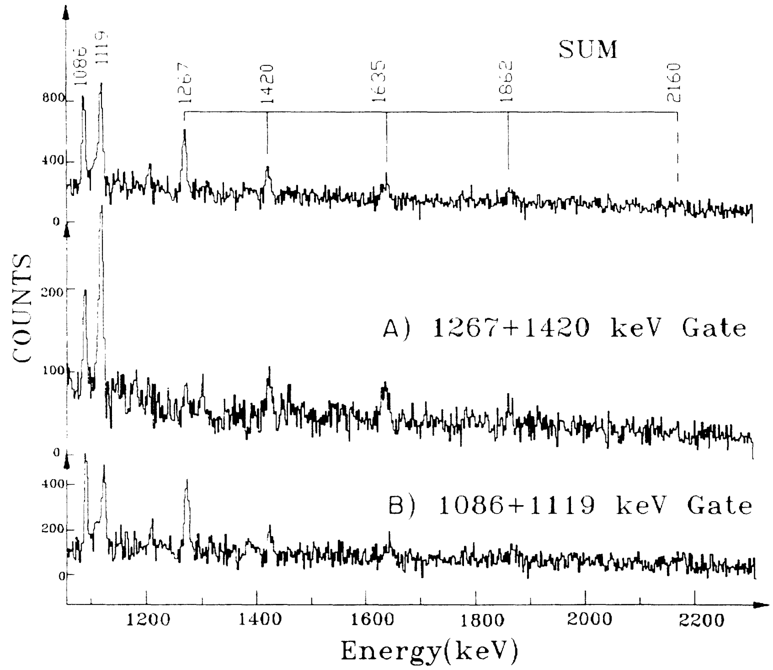

FIG. 1. Coincidence spectrum which shows: A) the sum of the 1086 and 1119 keV gates and B) the sum of the 1267 and 1420 keV and the spectra label by SUM as the sum of A) and B) spectrum. These results give evidence to establish four new γ-ray transitions, namely 1267, 1420, 1635, and 1862 keV and tentatively one with 2160 keV energy. Then the positive parity band reaches the angular momentum of tentatively $I^{\pi}=(24^{+})$.

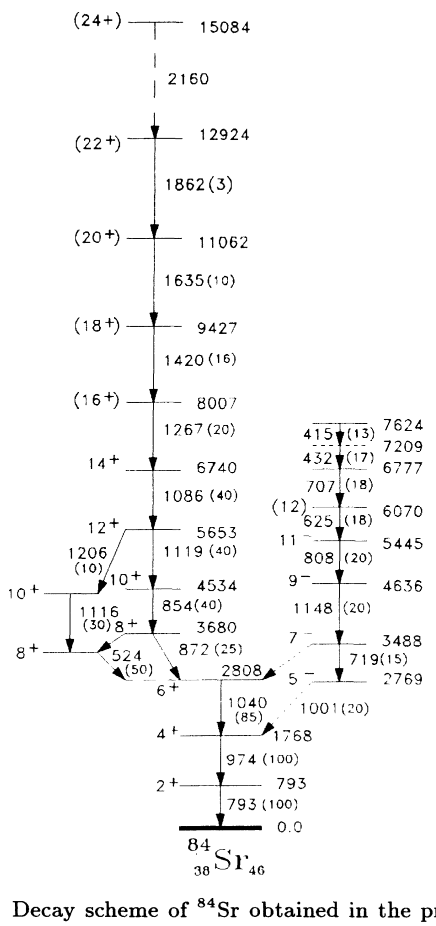

FIG. 2. Decay scheme of ^{84}Sr obtained in the present experiment. The order between the 415 and 432 keV γ rays is uncertain. Previous works establish the decay scheme up to the I^{π} = 14^{+} 6740 keV energy and I^{π} = (12) 6070 energy nuclear levels. The addition of several new γ rays define a region of constant moment of inertia for a frequency higher than $\hbar\omega$=0.58 MeV.

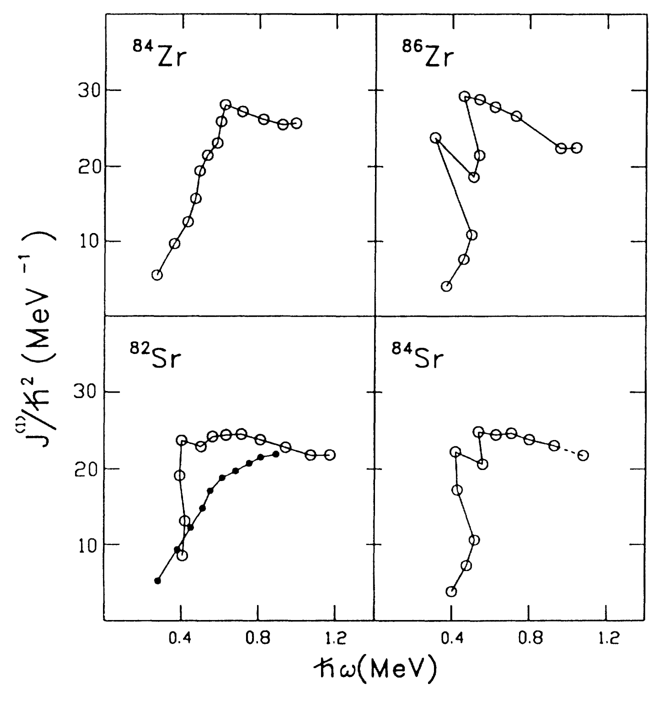

FIG. 3. Evolution of the kinematic $j^{(1)}$ moment of inertia as a function of angular frequency for the positive parity band in the ^{84}Sr nucleus compared with similar bands of neighboring nuclei. In particular for the ^{82}Sr nucleus the figure shows the ground-state band (small circle) and the positive parity band, with bandhead at 1175.6 keV energy (circle). The addition of new states in the decay scheme of ^{84}Sr nucleus clearly establish that, for frequency higher than 0.58 MeV, the kinematic moment of inertia approaches an almost constant value of about 24 MeV^{-1}.

the ^{88}Mo nuclei, isotone of ^{84}Sr, up to about 11 MeV of excitation energy and $23\hbar$ spin.

An alternative way to represent the experimental data is through the introduction of collective parameters: namely, the moment of inertia as a function of angular frequency. Figure 3 shows the positive parity γ-ray cascade of ^{84}Sr compared with similar cascades of neighboring nucleus as ^{82}Sr [1] and ^{84,86}Zr [6,7]. From the observation of Fig. 3 emerges that the average shape of the curves is similar. It shows a common sudden rise and then a saturation at comparable value of the moment of inertia. The first part could be related to the "spherical" structure since the constant γ-ray transition energy with spin, characteristic of the vibrational structure, entails a constant frequency. On the other hand, the constant moment of inertia independent of the frequency is characteristic of a rigid rotor. This sudden change in the moment of inertia could be attributed to the effect of a broken pair of quasiparticles and subsequent alignment. From the plots of the dynamical moment of inertia with frequency for neighboring ^{80}Sr and ^{82}Sr [8,1] nuclei it is possible to determine the crossing frequency in which the two-quasiparticle proton band ($\hbar\omega$ =0.55 MeV) and neutron band ($\hbar\omega$=0.75 MeV) occur. From these results, the first change in $J^{(1)}$ is well correlated with the alignments of a proton pair. On the other hand, the convergence of all these bands to a value close to the rigid moment of inertia is not possible to only attribute it to the disappearance of pairing correlation. The theoretical analysis performed on ^{82}Sr in [1] described the experimental data without using pairing and the author concluded that it is not a necessary nor sufficient condition to indicate the absence of pairing. In addition, a recent study in the transitional nucleus ^{86}Zr [7] to high spins established the positive parity yrast sequence which extends from spin I=14 up to $24\hbar$, shown in Fig. 3. They measured the electromagnetic transition rates of these states and found very small $B(E2)$ values with $B(M1)$ staggered and large. This measurement is difficult to describe as a result of a rotational model. A recent review article by Tabor [9] analyzed the convergence of the moment of inertia at a frequency higher than $\hbar\omega$=0.6 MeV in detail. The survey indicates interesting trends but suggests a need for much more experimental work to describe in greater detail the nuclear structure of this spin region.

Concluding, the present experiment determined three more states related to the negative parity cascade and four states in the positive parity one covering the frequency range between $\hbar\omega$=0.58 and 0.87 MeV. The addition of these states clearly identified, for the ^{84}Sr nucleus, a change in nuclear structure above a certain frequency. The analysis establishes that for a frequency higher than 0.58 MeV the kinematic moment of inertia approaches an almost constant value of about 24 MeV^{-1}. With the purpose of elucidating the nuclear structure of these states at this high rotational frequency a more sensible experimental parameter such as the lifetime measurement should be performed.

Note added. We have learned of preliminary results of C. J. Lister *et al.* reported in *Proceedings of the 21st International Symposium on Rapidly Rotating Nuclei*, Tokyo, Japan, 1992, edited by K. Furuno, N. Onishi, K. Matsuyanagi, F. Sakata and Y. Gono, Nucl. Phys. **A557**, 361c (1993). Their results are in agreement with those presented here.

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