Hybridized bands and parity splitting in the odd-odd nucleus $^{220}$Ac

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The high spin state structure of the nucleus $^{220}$Ac was investigated by means of the $^{209}$Bi($^{14}$C, 3$n$) reaction. In beam γ ray spectroscopy was carried out using the Château de Cristal multidetector array. Gamma ray multipolarities were established by extracting directional correlation ratios from the Ge–Ge coincidence data and by intensity balance considerations. The level scheme, established up to 18 h above the lowest observed state, consists of three alternating parity bands. The data are interpreted in terms of the reflection asymmetric shapes of the nucleus. The analysis of the parity doublet candidates does not show the decrease of the parity splitting predicted for an odd-odd nucleus.

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1. Introduction

It has been recognized for some time that the concept of octupole deformation plays an important role in the interpretation of nuclear structure properties of light actinide nuclei. This deformation manifests itself by the occurrence of alternating parity bands, often of clearly rotational character, by the enhancement of the $E1$ transitions and, for odd mass nuclei, by the presence of parity doublets in the level schemes.

In Fr, Ra, Ac and Th isotopes, the high-spin state studies were limited to even-even or odd mass nuclei, with the exception of recent work on the doubly odd $^{218}$Ac [1, 2] and $^{216}$Fr [3] nuclei. The latter are the lightest actinium and francium isotopes possessing an octupole deformation and their alternating parity bands display the irregular energy-vs.-spin behavior, typical of transitional nuclei. The present study is devoted to another odd-odd nucleus, $^{220}$Ac, where both the quadrupole and octupole deformations are expected to be important. Preliminary results have already been reported elsewhere [3, 4].

The spectroscopic investigation of reflection-asymmetric deformations in odd-odd nuclei is especially interesting because it could provide a check on the theoretical expectation [5] that the parity splitting, i.e. the energy splitting between the two members of a parity doublet, is considerably reduced compared to those in the neighbouring odd-A nuclei. Since it is observed [6] that the parity splitting in the doubly even case is reduced for odd-proton and for odd neutron nuclei, it is foreseen that both the odd proton and the odd neutron will act on the parity splitting of an odd-odd nucleus, yielding therefore a further reduction of the energy difference.

2. Experimental procedure and analysis

Excited states in $^{220}$Ac were populated by means of the $^{209}$Bi($^{14}$C, 3$n$) reaction at the Strasbourg MP tandem accelerator. A three point excitation function led to the choice of a bombarding energy of 72 MeV for the γ–γ coincidence measurements. For that part of the experiment the target consisted of 5.5 mg/cm$^2$ of bismuth, sandwiched between two carbon foils of 10 µg/cm$^2$ and positioned at 45° with respect to the beam axis. The γ rays were detected with a versatile multidetector $4\pi$ array called “Château de Cristal”, whose description may be found in [7]. In the present experiment, the number of active BaF$_2$ scintillation counters of the inner array used as multiplicity and sum-energy filter was reduced from 38 to 26. The twelve BaF$_2$ counters which are pierced to give the Ge detectors a direct view of the target were made inactive by setting lead collimators in front of them. This was done in order to avoid multiple γ scattering in these detectors in the vicinity of the drilled passages and hence to improve the quality of the γ spectra. Ten Compton-suppressed Ge detectors (having efficiencies of $\sim$20%) were positioned at ten of the twelve spots defined by the intersection of three vertical planes (at 30°, 90° and 150° relative to the beam direction) and two rings (above and below the medium plane of the
Château de Cristal), the distance of the Ge detectors to the target being 26 cm. Two planar Ge detectors, also surrounded by anti-Compton devices, were set at the two remaining spots, namely at 30° and 90° on the lower ring. The Be windows of the planar detectors were covered by 3 mm thick aluminum foils. The utilization of the planar Ge detectors was justified \textit{a posteriori} by the presence of low γ-ray transitions such as the γ-ray triplet in the 105 to 108 keV region, where also actinium Kγ lines are present (see Fig. 1).

Channel widths of 0.18 and 0.25 keV were chosen for the planar and the large Ge detectors, respectively. Energy and efficiency calibrations were performed using $^{152}$Eu and $^{182}$Ta radioactive sources and the former ones were checked for the in-beam measurements using the known energies of $^{219}$Ac lines [8, 9].

During the experiment, data were recorded in list mode for each $\gamma - \gamma$ coincidence detected in Ge detectors: the corresponding energies and the labels of the Ge detectors, the corresponding times with respect to that of the first BaF$_2$ counter which was triggered, the number of BaF$_2$ that were hit and the total energy measured by these counters.

The off-line analysis was performed by constructing several bidimensional matrices. They served to check for possible delayed transitions and to define cuts on the sum-energy vs. multiplicity plane which enhance the $3n$ channel. The changes in the gamma spectrum resulting from different multiplicity and sum-energy conditions are shown in Fig. 2 which gives a clear indication of the channel selectivity obtained in the present experiment. Several $E_1 - E_2$ matrices where used either to construct the level scheme or to extract directional correlation from oriented nuclei (DCO) ratios. The method used to analyse these latter matrices is reported elsewhere [10].

Gamma ray multipolarities were established by extracting DCO ratios [11] from Ge–Ge coincidence data. In the present experiment, such a ratio $R$ was defined as the ratio of the coincidence rate of a $\gamma_1$ transition detected at 90° and a $\gamma_2$ transition detected at (30°/150°) to the coincidence rate of $\gamma_1$ (30°/150°) and $\gamma_2$ (90°). After correction for the relative efficiency of the Ge detectors, $R$ is unity for stretched transitions of the same type, $R > 1$ for $\gamma_1$ being a dipole and $\gamma_2$ a quadrupole transition, and $R < 1$ in the opposite case. The sharp distinc-

![Fig. 1. Low-energy γ-ray spectra emphasizing the presence of the 106, 107 and 108 keV γ transitions in the different alternating parity bands. Note the enhancement of the peak at 77 keV when a gate is set on the 265 keV γ-transition](image1)

![Fig. 2. Portion of the gamma spectrum with different conditions on the inner array of the “Château de Cristal”. K denotes the fold, i.e. the number of BaF$_2$ counters hit. For each K value, the sum-energy was divided in four regions with the same number of events: E1 to E4. The numbers on top of the peaks are their energies (in keV)](image2)