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LIFETIME MEASUREMENT OF THE CORRELATED CONTINUUM GAMMA RAYS IN ^{170}Hf

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Continuum gamma rays are generally emitted at the early stages of the gamma decay of a compound nucleus. These gamma rays are from states with higher angular momentum and excitation energy than the discrete gamma rays. Therefore, from the study of continuum gamma rays it is possible to obtain information on nuclear properties in regions unreachable through studies of discrete transitions.

It is known experimentally that in most nuclei the continuum gamma rays are stretched E2 in nature and that they follow rotational-like sequences (i.e., energy increases with spin). The "singles" continuum spectra show a high energy edge which corresponds to the maximum spin of the residual nucleus. As more angular momentum is brought into the compound nucleus, the edge moves to higher energy. In a two-dimensional gamma-gamma coincidence matrix, the rotational-like behavior shows up as a valley along the $E_1 = E_2$ diagonal and as ridges parallel to the valley. The valley is due to the fact that in a rotational cascade there are no two gamma rays with the same energy and the ridges are from the two consecutive gamma rays in the rotational sequence. The separation of the ridges is directly proportional to the nuclear moment of inertia.

Recent studies have shown that only a small fraction of the expected continuum intensity is observed in the ridge structure which has a width of about 20 keV. Level-mixing calculations for the region above the yrast line indicate that the effect of the damping of the collective strength is to spread the correlation through a region as wide as 200 keV. Such a large width will lead to a reduction of the intensity of the ridge structure that rises above the valley. In addition, this rotational damping will also change the lifetime of the E2 decay. Hence, a measurement of the lifetime of the gamma-ray continuum can provide information on the degree of rotational damping.

Lifetime measurements of the continuum gamma rays were first[1] carried out on singles spectra using the Doppler-Shift Attenuation Method (DSAM). Spectra from experiments with a thin target and a gold-backed target were compared and from the difference in the Doppler-shift of the edge of the E2 continuum, the lifetime of the gamma rays near the edge was derived. The results indicated that the collectivity of the continuum gamma rays is as high (and possibly higher) than the low-spin rotational states. However, these experiments have limited value because they were done with NaI detectors which have low energy resolution and because the singles method can only measure the lifetimes of gamma rays near the edge. In the current measurements we have applied the DSAM to the full gamma-gamma correlation matrix, enabling us to determine the lifetime of the ridge in ^{170}Hf over a large range of energy. With our Compton Suppression Spectrometer System, it was possible to carry out these measurements with good energy resolution and a high peak-to-Compton ratio.

The experiments were carried out with a 195 MeV ^{44}Ca beam from the HHIRF tandem accelerator. Two ^{130}Te targets were used in separate runs. A 1 mg/cm^2 target on a 16 mg/cm^2 gold backing was used for the DSAM measurement and a thin target of thickness 1 mg/cm^2 was used for comparison. The gamma rays were detected in 20 anti-Compton shielded Ge detectors placed in a compact support structure with a target to Ge detector distance of about 12 cm. Triple-coincidence data were taken at a rate of 1000 events per second. We collected 150 x 10^6 events with the backed target and 50 x 10^6 events with the thin target.

Two-dimensional E_γ vs. E_γ matrices were generated from these data. For the thin target, data were corrected for both the gain and the angular dependence of the Doppler shift. From the data with the backed target, a matrix was generated with coincidence events between the four 45° detectors and the four 135° detectors. Only the gain was corrected for this matrix. Thus, depending on the lifetime, the gamma ray will show a different amount of Doppler-shift. Since the stopping time of Hf in Au is about 2.4 ps, states which decay within 0.2 ps after the formation of the compound nucleus will show almost full Doppler-shift and states which decay after 2.4 ps will show no shift. States which decay between 0.2 and 2.4 ps will show varying amounts of shift making it possible to extract their lifetimes. To measure the shifts, the 2-D matrices were cut perpendicular to the diagonal and 1-D spectra were obtained by projection. Cuts were made in 50-keV steps from 700 to

1100 keV on both matrices and Fig. 1 shows the comparison of several of these projected spectra.

It can be seen from these data that from 700 keV to 1000 keV the shift increases from 12% to 90% of the fully-shifted value, indicating a movement toward shorter lifetimes. Since the apparent lifetime reflects the total time from the formation of the compound nucleus to the emission of the gamma ray, to obtain the collectivity of a given transition, we have to understand the lifetimes of all the preceding gamma rays. The total decay time is dependent on the spin I_i of the starting point of the cascade, the energy of the gamma rays in the cascade, and the B(E2) values of the transitions. In a simple model, if a constant value for the moment of inertia is assumed, the gamma-ray energy can be calculated by $E_\gamma = (4I-2)/2\ \mathscr{J}/\hbar^2$; and if a constant value for Q_t is assumed, the B(E2) can be obtained by the expression

$$B(E2) = (16\ \pi/5)\ Q_t^2 <I\ 0\ 2\ 0|\ I-2\ 0>^2 .$$

The value of I_i can be determined from the average multiplicity of the gamma ray. Using this information, together with the recoil velocity calculated as a function of time from the stopping power, we can calculate the expected Doppler shift as a function of the gamma-ray energy. Figure 2 compares the calculated results with the experimental values. In these calculations, we used $I_i = 50$ which is determined from our measured average gamma-ray multiplicity, $2\mathscr{J}/\hbar^2$=114 MeV^{-1} which reproduces the separation of the ridges. The three curves correspond to

Q_t values of 6, 7, and 8 eb, where 7 eb is the value for 2+ → 0+ transition of ^{170}Hf.

The experimental results in Fig. 2 indicate that the collectivity of gamma rays with energy less than 900 keV is smaller than that of the 2+ → 0+ transition, and above 900 keV the collectivity is higher. The reduction of the collectivity at E_γ < 900 keV has been observed[2] in many nuclei. It is interpreted as the change of the nuclear shape to smaller β deformation or to more triaxial or oblate deformation ($\gamma > 0$) due to the rotational alignment of high-j particles. The increasing of the collectivity at higher energies can also be due to a shape change. However, it is possible that this increase could be due to rotational damping. According to the calculation, the spreading width of the E2 strength for A = 160 nuclei is about 100-200 keV at an excitation energy of 2 - 4 MeV. Due to the E_γ^5 factor in the E2 transition rate, such a spread will increase the transition rate and reduce the lifetime by a factor of 10 - 30% which is comparable to our experimental values.

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References

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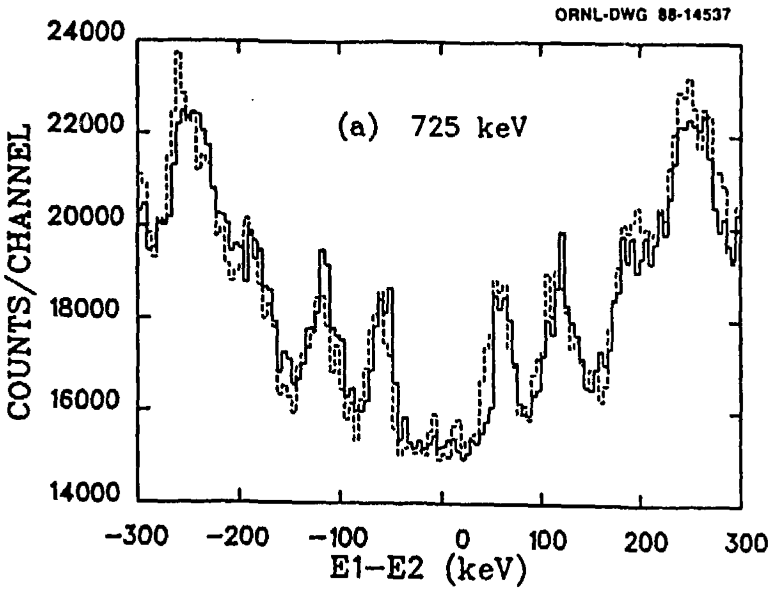
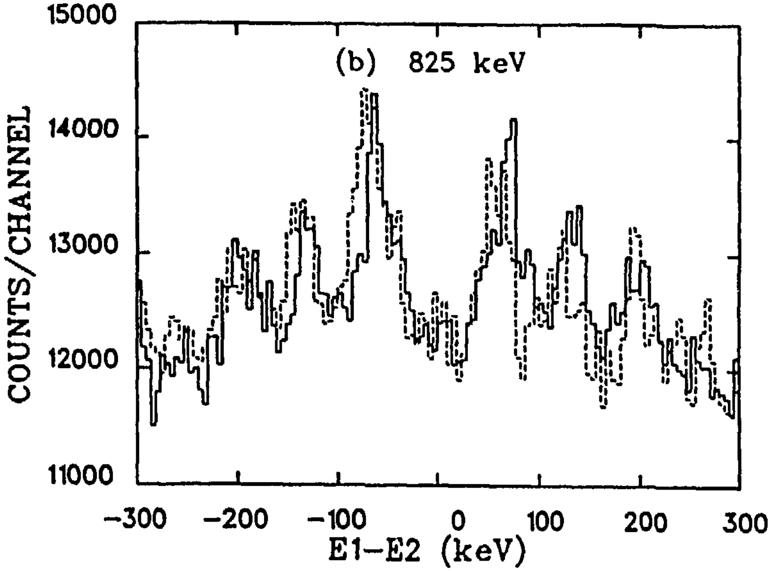
2) M. P. Fewell, N. R. Johnson, F. K. McGowan, J. S. Hattula, I. Y. Lee, C. Baktash, Y. Schutz, J. C. Wells, L. L. Riedinger, M. W. Guidry and S. C. Pancholi, Phys. Rev. C 37 (1988) 101

1. Gamma-ray spectra from backed-target (solid curves) and thin-target (dashed curves) experiments. Spectra were obtained by cutting and projecting the 2-D matrix perpendicular to the $E_1 = E_2$ diagonal in 50-keV steps centered at E_γ = 725 (a), 825 (b), 875 (c) and 925 keV (d), respectively.

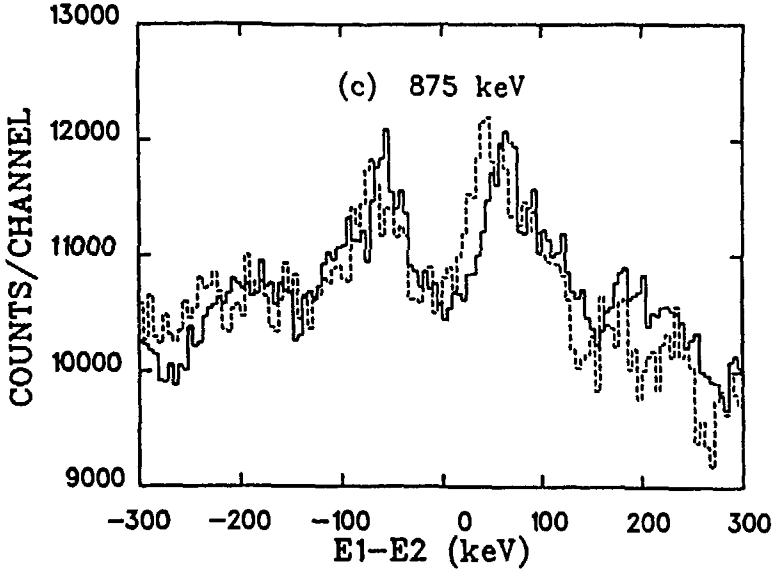
2. Measured and calculated Doppler shift as a function of gamma-ray energy. The calculations were carried out using $I_i = 50$, $2\mathcal{J}/\hbar^2$ = 114 MeV^{-1} and Q_t = 6, 7, and 8 eb.

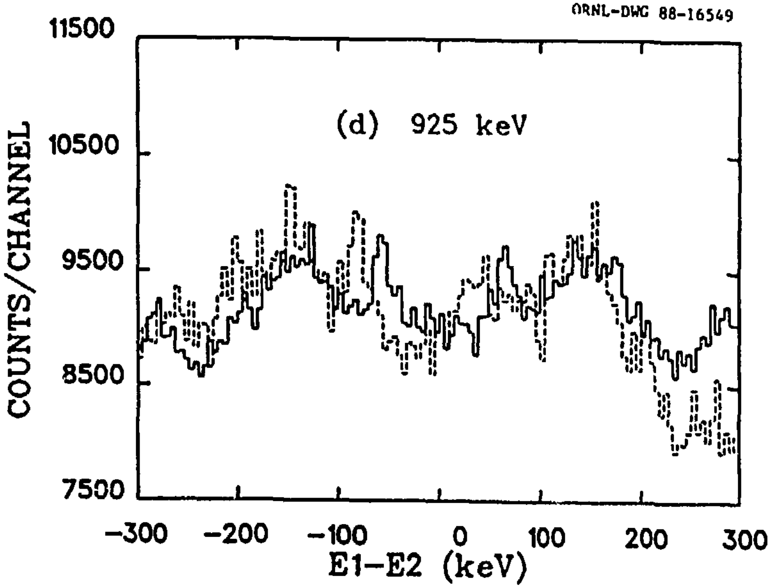

ORNL-DWG 88-14537
(a) 725 keV
COUNTS/CHANNEL
24000
22000
20000
18000
16000
14000
−300
−200
−100
0
100
200
300
E1−E2 (keV)

ORNL-DWG 88-14539



ORNL-DWG 88-16548




ORNL-DWG 88-16549
(d) 925 keV
COUNTS/CHANNEL
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10500
9500
8500
7500
−300
−200
−100
0
100
200
300
E1−E2 (keV)

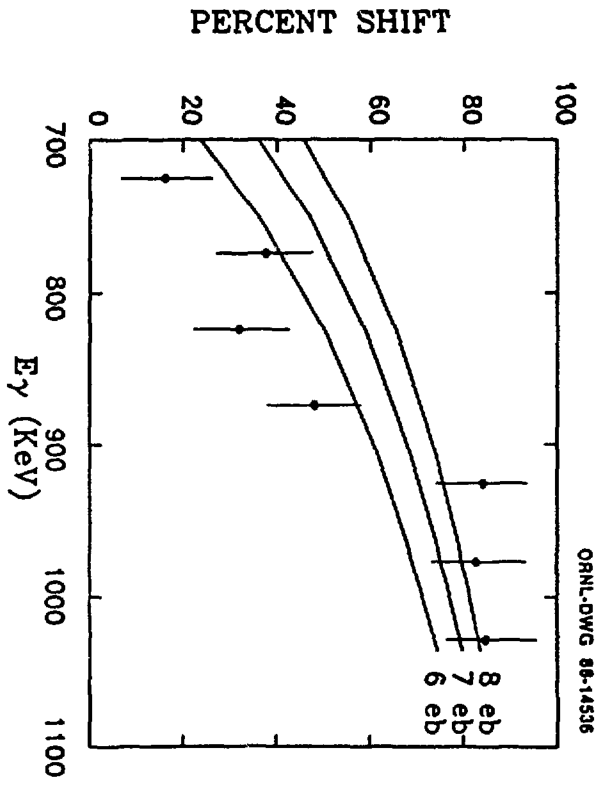
PERCENT SHIFT
0
20
40
60
80
100
700
800
900
1000
1100
Eγ (KeV)
ORNL-DWG 88-14536
8 eb
7 eb
6 eb

Fig.2