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THE REACTION DEPENDENCE IN THE γ-DECAY OF HIGHLY EXCITED RARE EARTH NUCLEI

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Abstract:

The γ-decay from states with low spin at high excitation energy has been studied using the $(^{3}He,{}^{3}He')^{162}Dy$ and $(^{3}He,{}^{4}He)^{162}Dy$ reactions. The γ-ray spectra obtained in the two reactions are almost identical and do not reveal any reaction dependence.

In the experiments reported (1-3) on the decay of nuclei which have been excited by means of the (^3He,^4He) reaction, the gross structure of the γ-spectra is indeed as expected for statistical decay. However, two broad bumps superimposed on the statistical spectrum, were observed. One bump was located at an energy of 0.8 - 1.2 MeV in even-even nuclei (1) and one bump with energy 2.0 - 2.5 MeV so far reported only in odd nuclei (2).

Mechanisms that could explain these broad structures have been suggested in earlier papers (1,2), but so far, not enough data have been available to allow definite conclusions to be drawn.

The broad bumps account for a considerable fraction of the total γ-ray intensity, and one may ask why they have not been observed in other γ-decay studies, e.g. in the (α,2n) reaction studied by Sie et al.(4). Are these prominent bumps only associated with the (^3He,^4He) reaction employed in the preparation of the γ-emitters referred to above ?

To look for a possible reaction dependence, we have compared the γ-spectra for the nucleus ^{162}Dy produced in the ^{163}Dy(^3He,^4He)^{162}Dy reaction and in inelastic ^3He-scattering. The inelastic process excites preferentially the collective quadrupole and octupole vibrational modes, while the (^3He,^4He) reaction mainly populates two-quasiparticle states via transfer to single-hole states with large particle angular momentum.

The experiments were performed by bombarding the isotopically enriched ^{162}Dy and ^{163}Dy targets with 45 MeV ^{3}He particles from the Scanditronix MC 35 cyclotron at the University of Oslo. The charged particles from the reactions were detected in four particle telescopes all positioned at a scattering angle of 40° relative to the beam direction. Each telescope consisted of one 140 μm and one 3000 μm Si-detector and was placed as close as possible to the target to give a maximum solid angle (250 msr). The γ-rays were measured with two 12.7 cm x 12.7 cm NaI and two Ge counters. Details of the set-up are given in ref. (3).

The experimental intensities of the yrast transitions normalized to the number of cascades, are shown in fig. 1. The data shown are measured with Ge-detectors in coincidence with emerging ^{4}He particles leaving the ^{162}Dy nucleus with an excitation energy between 2.4 and 8.2 MeV. The absolute normalization is somewhat arbitrary since the feeding to the 0^{+} and 2^{+} yrast states is unknown. However, fig. 1 clearly shows that on the average the yrast states are entered with 2ℏ less angular momentum in the inelastic scattering process when compared to the pick-up reaction.

The yrast intensities can be compared with a simple model calculation where it is assumed that a non-yrast state with spin I decays with equal probabilities to states with spins I-1, I and I+1. For the excitation region of interest (E_x=2.4-8.2 MeV) the average number of non-yrast γ-transitions is known (5) to be ~2.5. With these assumptions the calculated yrast intensities for the initial average spins of I=2,4 and 6 are drawn as solid curves in fig.1. If the decay follows roughly the spin-selection mechanism described above, we estimate that the initial spin populated prior to γ-radiation are $I=(3.5\pm1.0)\hbar$ and $(5.5\pm1.0)\hbar$ for the (^{3}He,^{3}He') and (^{3}He,^{4}He) reactions respectively. This is consistent with the assumption that the inelastic scattering process populates low spin vibrational states and the transfer reaction picks out $h_{9/2}$,$h_{11/2}$ and $i_{13/2}$ neutrons. Thus, the observed spin distributions emphasize the difference in the two reaction mechanisms.

Figure 2 shows the NaI γ-ray spectra of ^{162}Dy, obtained in the two reactions. The data are taken in coincidence with outgoing particles which populate the levels at excitation energies of 2.4-8.2 MeV. The two spectra reveal striking similarities. The yrast part of the spectrum ($E_\gamma < 0.5$ MeV) shows more strength in the pick-up reaction, consistent with the Ge spectra discussed above.

The unfolded NaI spectra, displayed in fig. 3 exhibit large structures, which are not expected in the decay within a Fermi-gas picture. We have calculated such Fermi-gas γ-ray distributions using Monte Carlo simulations according to the procedure of ref.(6). The results are shown as dotted curves in fig.3. The calculated curves are scaled to represent a continous background in the observed spectra. Using the Fermi gas distribution as "background", the position (E_γ), the width (σ_γ) and strength (I_γ) of the 1 MeV and 2.5 MeV bumps may be evaluated (see Table 1). A comparison of these quantities deduced from the (^{3}He,^{3}He') and (^{3}He,^{4}He) reactions again verify the similarities in the two γ-ray spectra.

We notice that the so-called 1 MeV bump observed in ^{142}Dy actually consists of two components. The lower one is located at 0.9 MeV γ-ray energy and carries about twice the strength found in the other component at $E_\gamma \sim 1.2$ MeV. The 2.5 MeV bump is even more complex and is interpreted as one broad bump as a whole.

The γ-ray spectra may be divided into three parts: yrast transitions, continuum transitions and transitions associated with the bump structures, each with a given γ-ray multiplicity. In fig.4 is displayed the average number of γ-rays per cascade contributing to the various parts of the spectra. The multiplicities for yrast transitions are deduced from the data of fig.1. For the non-yrast γ-radiation we find that around one γ-ray per event constitutes the continuum part of the spectra. The three bumps carry a significant fraction of the non-yrast radiation (~ 58%) and play an important role in the total decay pattern.

In summary, a comparison of the two reactions should reveal possible reminiscences of the formation process in the γ-decay. Although states of different structures are populated, the observed γ-ray spectra, which contain large bumps, are almost identical in the two cases. Hence, no reaction dependence is observed. This is contrary to the situation in lighter nuclei where such a dependence has recently been found (6). The result supports the picture of a fully thermalized nucleus as a source of the γ-radiation. We conclude that the particular shape of the γ-spectrum is characteristic for decay of highly excited low spin states in this nuclear mass region.

Figure captions

Fig.1 Probability for population of yrast states in the γ-decay from E_x=2.4–8.2 MeV.

Fig.2 Gamma-ray spectra from the $^{162}Dy(^3He,^3He')^{162}Dy$ and $^{163}Dy(^3He,^4He)^{162}Dy$ reactions. The ^3He beam energy was 45 MeV.

Fig.3 Unfolded γ-ray spectra. The dotted curves are calculated with a Fermi gas model.

Fig.4 The average number of γ-rays contributing to the yrast bump and the continuum part of the γ-spectra from E_x=2.4–8.2 MeV.

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Table 1 Comparison of γ-ray bumps

Reaction	E_γ (MeV)	σ_γ (MeV)	I_γ $^{a)}$
(^3He,$^3He'$)	0.86(3)	0.31(8)	0.22(3)
(^3He,^4He)	0.85(3)	0.32(8)	0.26(3)
(^3He,$^3He'$)	1.27(2)	0.31(8)	0.12(2)
(^3He,^4He)	1.18(2)	0.32(8)	0.16(2)
(^3He,$^3He'$)	2.5(2)	1.2(1)	0.21(2)
(^3He,^4He)	2.5(3)	1.6(2)	0.19(2)

$^{a)}$ relative to total intensity of non-yrast γ-rays.

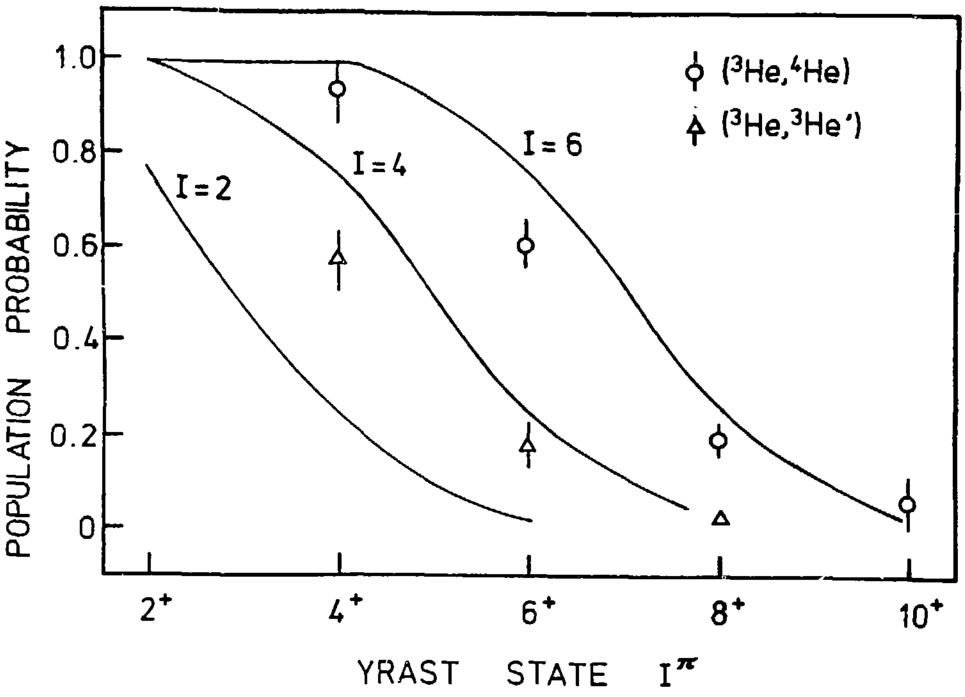
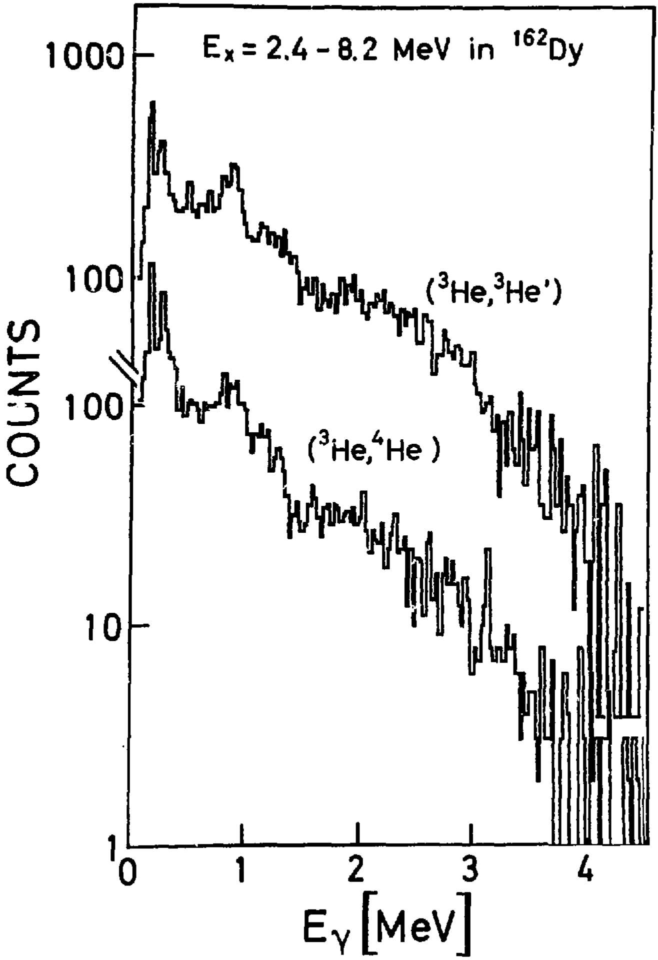

(³He,⁴He)
(³He,³He')
I = 6
I = 4
I = 2
1.0
0.8
0.6
0.4
0.2
0
POPULATION PROBABILITY
2+
4+
6+
8+
10+
YRAST STATE Iπ

Fig. 1



E_x = 2.4 - 8.2 MeV in ^{162}Dy
1000
100
100
10
1
COUNTS
(^{3}He,^{3}He')
(^{3}He,^{4}He)
0
1
2
3
4
E_γ [MeV]

Fig. 2

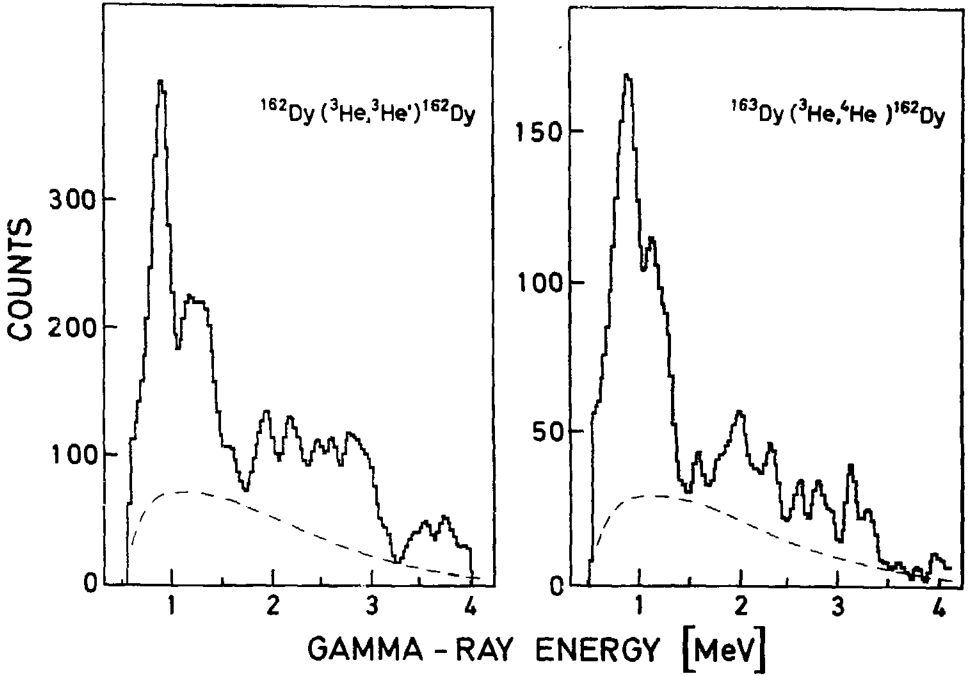

COUNTS
300
200
100
0
150
100
50
0
1
2
3
4
$^{162}Dy(^{3}He,^{3}He')^{162}Dy$
$^{163}Dy(^{3}He,^{4}He)^{162}Dy$
GAMMA - RAY ENERGY [MeV]

Fig. 3

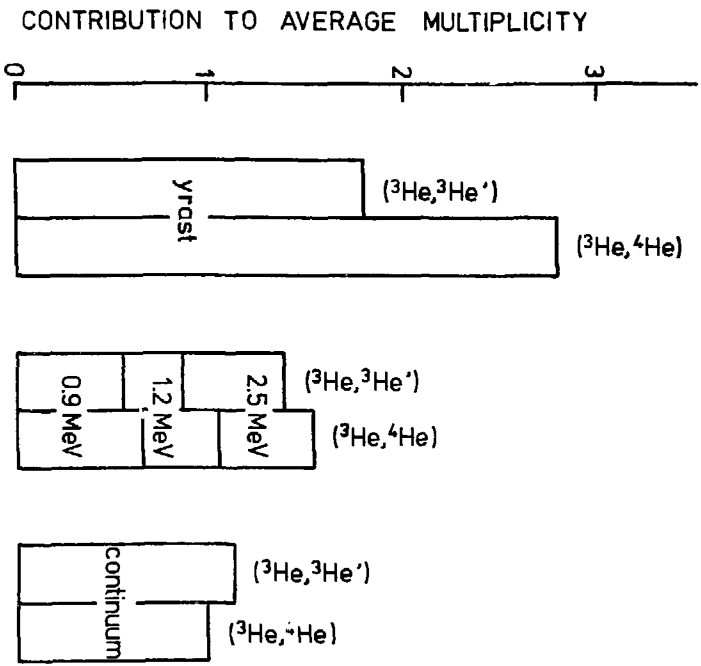

CONTRIBUTION TO AVERAGE MULTIPLICITY
0
1
2
3
yrast
(3He,3He')
(3He,4He)
0.9 MeV
1.2 MeV
2.5 MeV
(3He,3He')
(3He,4He)
continuum
(3He,3He')
(3He,4He)

Fig. 4