LEVEL DENSITIES EXTRACTED FROM FIRST-GENERATION γ–RAY SPECTRA*

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The level density of low-spin states ($0 - 10\hbar$) in ^{162}Dy has been determined from the ground state up to approximately 6 MeV of excitation energy. Levels in the excitation region up to 8 MeV were populated by means of the ^{163}Dy(^{3}He,α) reaction, and the first-generation γ-rays in the decay of these states have been isolated. The energy distribution of the first-generation γ-rays provides a new source of information about the nuclear level density over a wide energy region. A broad peak is observed in the first-generation spectra, and we suggest an interpretation in terms of enhanced M1 transitions between different high-j Nilsson orbitals.

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The structure of medium heavy nuclei at low spin and excitation energy in the range from 2–3 MeV up to 40 MeV has been the focus in the research at the Oslo cyclotron for more than one decade. In this region one expects the nucleus to undergo a structural change, characterized by the discrete levels and lines at low energy and the exhibition of statistical features when the energy increases. We want to investigate the nature of this transition.

The γ-decay from various excitation regions is expected to display different facets of this structure. The challenge is therefore to be able to isolate γ-transitions from certain intervals in energy and spin, and to study in a systematic way how these quantities influence the γ-decay.

An excellent source of information of this kind is the γ-decay following thermal neutron capture. This topic is discussed in another contribution (Tveter *et al.*). The present talk concentrates on γ-decay following the

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(^{3}He,α) pick-up reaction on deformed rare earth nuclei, where the applied technique provides the opportunity to study the first generation γ-rays as a function of excitation energy over a wide energy region. We will report on a study of the ^{162}Dy nucleus with emphasis on two aspects; the nuclear level density and favoured decay modes.

Photons emitted from an ensemble of excited states with energy E_x will describe an energy distribution determined by multipolarity, accessible levels and eventual structural factors. If the states are located sufficiently far above the yrast line, the properties of the individual levels will be less important. Then the statistical features will essentially determine the energy distribution of the photons, as given by [1]:

$$N_\gamma(E_x, E_\gamma) \propto \rho(U) \cdot E_\gamma^n \,, \tag{1}$$

where $U = E_x - E_\gamma$. The factor E_γ^n describes the dependence on the photon energy, while the level density at excitation energy U and in the populated spin interval is denoted $\rho(U)$. A commonly used expression for the level density based on the Fermi gas model is given by [2]:

$$\rho(U) \propto (U - E_{\mathrm{corr}})^{-2} \cdot \exp\left(4a(U - E_{\mathrm{corr}})\right)^{1/2} \,, \tag{2}$$

where $E_{\mathrm{corr}} = E_\Delta + E_{\mathrm{rot}}$. The quantity E_Δ is the pairing energy and E_{rot} the energy of the yrast line at the actual spin. The level density parameter a defines the general slope of the distribution.

The energy factor E_γ^n may depend on properties like spin, parity and other structural features. These additional factors may be related to the process used for preparation of the levels E_x, or to correlations in the decay channels. Provided that these quantities can be determined, Eq. (1) may be used for extraction of the nuclear level density $\rho(U)$.

In the actual energy region the (^{3}He,α) reaction may be considered as a direct pick-up of a neutron [3]. Hence the population takes place through the one-neutron components of the wave function of the target nucleus. The building up of a complete eigenstate is assumed to be a very fast process compared to the time necessary for the organization of photon emission. It is therefore likely that a full thermalization is obtained long before the emission of the photon. The energy distribution of the primary photons given by Eq. (1) requires that a full thermalization takes place. Violations of this condition will presumably be exhibited in the energy spectra.

The challenge from the experimental side is to isolate and determine the energy distribution $N_\gamma(E_x, E_\gamma)$ of the photons originating from the levels E_x. The population of each level will result in a cascade of γ-rays, of which only the first one is of interest in this connection. The separation between the primary or the first-generation γ-ray and the rest of the cascade can be

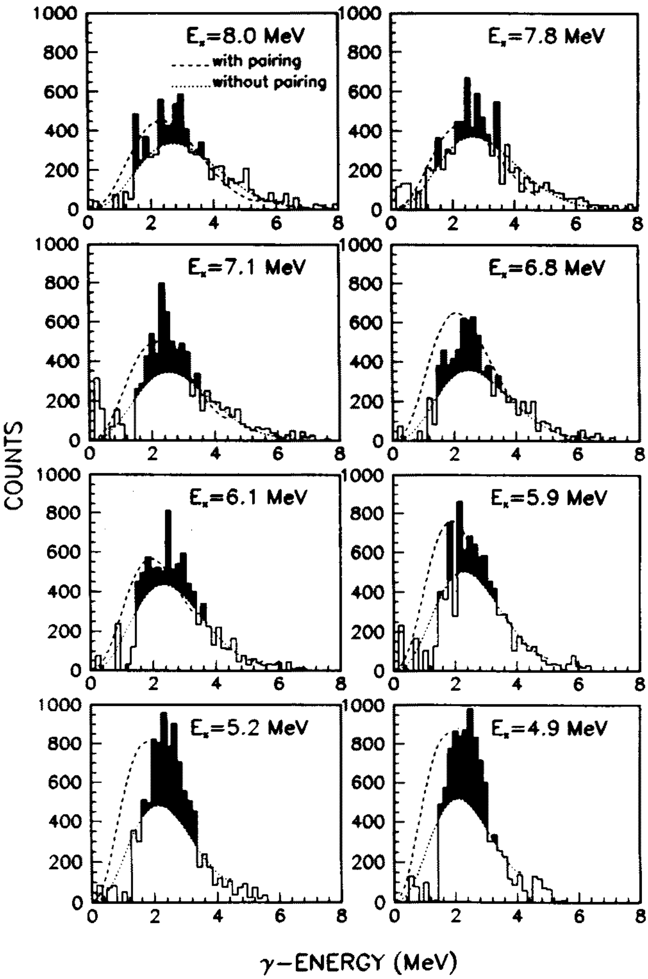

Fig. 1. First generation spectra from various excitation regions. The width of each bin is 240 keV. The two curves correspond to Fermi gas estimates with $a = 16.7$ MeV^{-1} and $n = 4.2$, with backshift 1.9 MeV (dashed) and without bakshift (dotted curve).

achieved by means of a subtraction technique, in combination with nuclear reactions where the exit channel contains two charged particles only. This technique is described in Ref. [4].

The reaction employed was the ^{163}Dy(^{3}He,α)^{162}Dy pick-up with a projectile energy of 45 MeV. The reaction products were recorded by means of the multidetector set-up CACTUS described elsewhere [5]. It consists of 8 Si particle telescopes, all placed in a forward angle of 45° relative to the beam axis, surrounded by 28 NaI γ-ray detectors with a total detection efficiency of approximately 10%.

First-generation spectra from different excitation regions are shown in Fig. 1. They are compared with Fermi gas approximations based on a level density parameter $a = 16.7$ MeV^{-1} and $n = 4.2$, which gives the best overall description of the complete data set [6]. The dashed curve is obtained with a full back-shift due to pairing, while the dotted curve corresponds to $E_\Delta = 0$. We have to conclude that a good description of the experimental first-generation spectra cannot be obtained by means of Eqs (1) and (2), with constant values for a and n. The peak structure located at $E_\gamma \approx 2.5$ MeV independent of the excitation energy E_x, indicates an explanation beyond a purely statistical model like the Fermi gas model. A peak with about the same energy and width has been observed [7] in the neighbouring nucleus ^{161}Dy, and it is likely that these findings have a common origin. Due to the population characteristics for the (^{3}He,α) reaction, we find it most probable to associate this peak with the suggested enhancement of

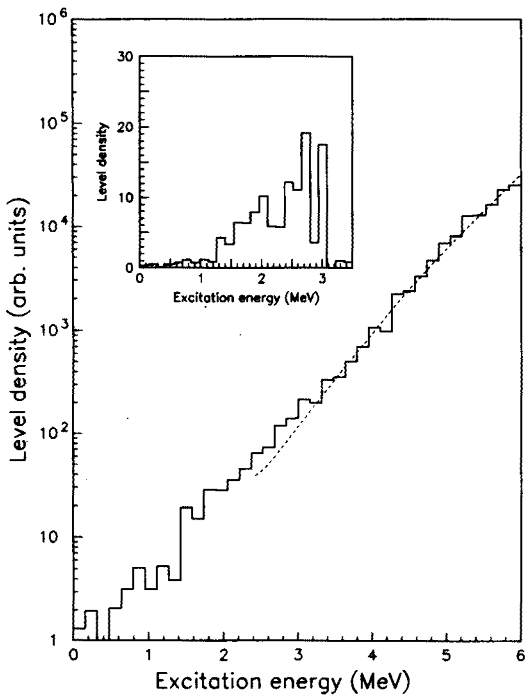

Fig. 2. The level density deduced from the four highest excitation bins. The dashed curve represent the best Fermi gas approximation with $a = 17.4$ MeV^{-1}, $E_\Delta = 1.9$ MeV and $E_{rot} = 0.3$ MeV. The insert shows the difference between the experimental and the theoretical level densities.

M1-transitions between orbitals originating from the same high-j spherical state, *e.g.* $h_{11/2}$ and $i_{13/2}$. This mechanism was first proposed by Chen and Leander [8].

The level density obtained from the sum of the four highest excitation bins is shown in Fig. 2. The spectrum reveals a near-exponential slope as expected for the level density function. The theoretical curve corresponds to a Fermi gas level density (Eq. (2)), with $a = 17.4$ MeV^{-1}, $E_\Delta = 1.9$ MeV and $E_{\rm rot} = 0.3$ MeV, which gives the best fit to the experimental level density in the excitation region from 3 to 5 MeV. The insert in Fig. 2 shows the difference between the experimental and the theoretical level densities. It is evident that the experimental level density is larger than the theoretical level density in the region up to about 3 MeV. This difference is trivial below approximately 1.5 MeV of excitation energy, since the collective degrees of freedom responsible for structure in the low energy regime is not accounted for by the Fermi-gas model. However, the significant excess in the region between 1.5 and 3 MeV is difficult to explain in terms of collective motion. One possible explanation which should be further investigated is that the additional levels in this region are due to pair correlations, which is expected to produce a dense grouping of levels in the vicinity of the energy 2Δ.

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