Level densities and γ-ray strength functions in ^{163,164}Dy

Hilde-Therese Nyhus, Ph.D. student UiO

Workshop Oslo, 2009

14. May, 2009

Overview

Motivation

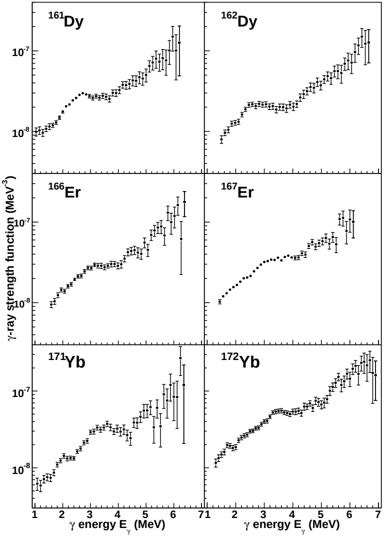
Level density:

- Fundamental to understand nuclear structure
- Extract thermodynamic properties

γ-ray strength function:

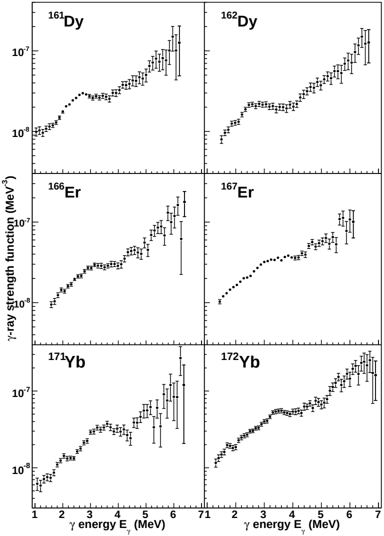
- Gives average electromagnetic properties

Motivation

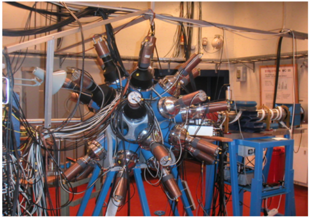


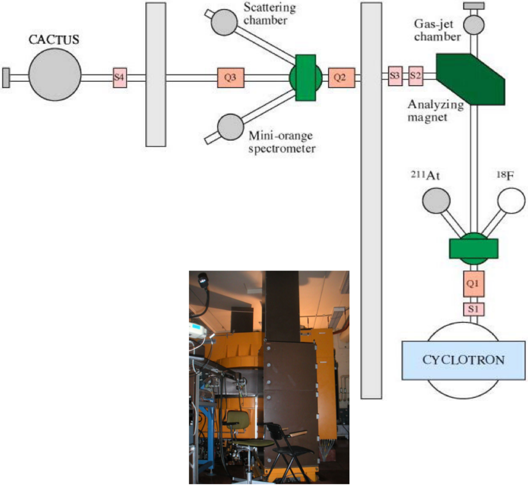
- Investigate the 3 MeV pygmy resonance
  - * Oslo method: Γ : 1.26 – 1.57 MeV in ^{160,161,162}Dy (for $T = 0.3$ MeV) through the reactions (^{3}He,^{3}He′) and (^{3}He,α)
  - * TSC method: Γ : 0.6 MeV in ^{163}Dy through the reaction ^{162}Dy(n,γ)^{163}Dy
- Extract level density and thermodynamic properties

Motivation



- Investigate the 3 MeV pygmy resonance
  - * Oslo method: Γ : 1.26 – 1.57 MeV in ^{160,161,162}Dy (for $T = 0.3$ MeV) through the reactions (^{3}He,^{3}He′) and (^{3}He,α)
  - * TSC method: Γ : 0.6 MeV in ^{163}Dy through the reaction ^{162}Dy(n,γ)^{163}Dy
- Extract level density and thermodynamic properties



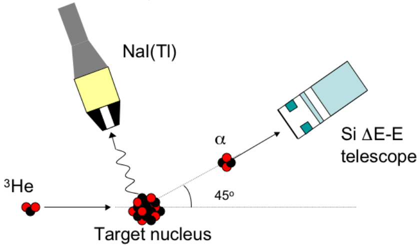


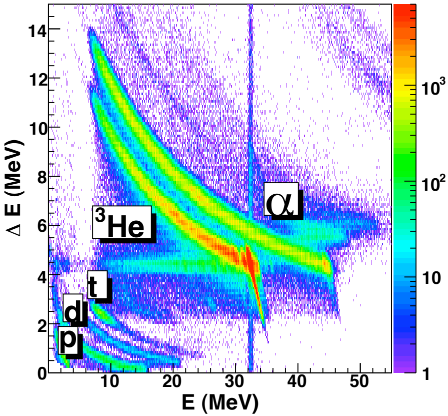
- **Beam**: 38 MeV, $^{3}\mathrm{He}$.
- **Target**: 1.73 mg/cm^2 thick foil of 98.5% enriched $^{164}\mathrm{Dy}$.
- **Detector array**:
  -28 NaI(TI) γ-detectors.
  -8 ΔE-E Si particle telescopes.

Particle identification

Inelastic scattering $^{164}Dy(^{3}He,^{3}He')\ ^{164}Dy$
Pick-up $^{164}Dy(^{3}He,\alpha)\ ^{163}Dy$

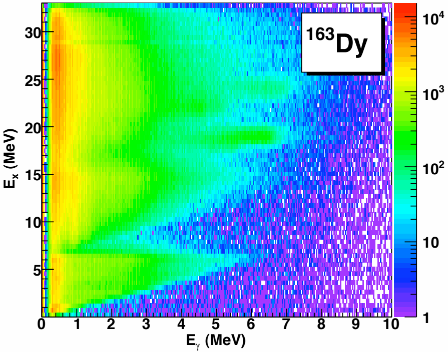
Particle-γ coincidences





Particle-γ-coincidence spectra

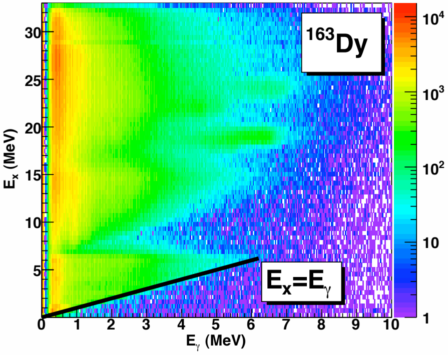
From the known Q-values the excitation energy of the nuclei are calculated from the detected ejectile energy by using reaction kinematics.



$\alpha - \gamma$-coincidence matrix, (^{163} Dy).

Particle-γ-coincidence spectra

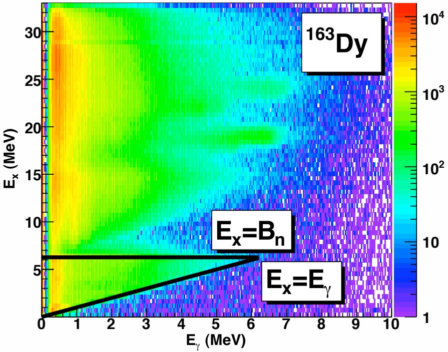
From the known Q-values the excitation energy of the nuclei are calculated from the detected ejectile energy by using reaction kinematics.



$\alpha - \gamma$-coincidence matrix, (^{163} Dy).

Particle-γ-coincidence spectra

From the known Q-values the excitation energy of the nuclei are calculated from the detected ejectile energy by using reaction kinematics.



$\alpha - \gamma$-coincidence matrix, (^{163} Dy).

The Oslo Method

Unfold all γ spectra

- : M. Guttormsen et al., NIM A374 (1996) 371

Apply the first-generation method

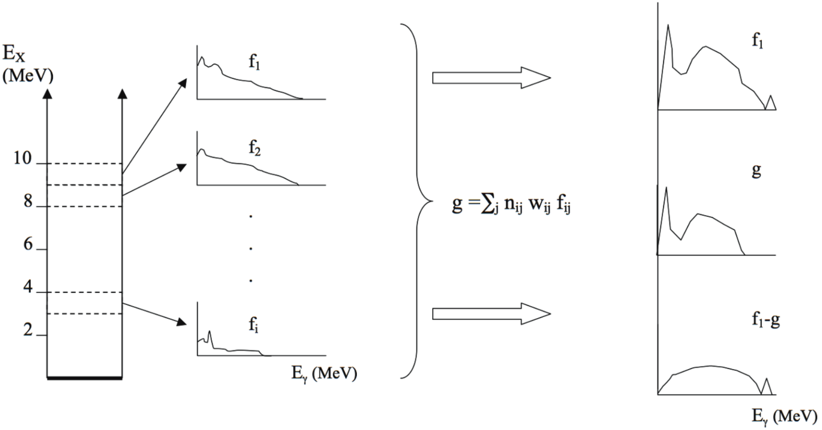
- : M. Guttormsen et al., NIM A255 (1987) 518

Extract level density and the γ-ray strength function

- :A. Schiller et al., NIM A447 (2000) 498

The first generation method

The first γ-rays emitted in each γ-decay cascade are isolated by using a subtraction method.



Brink-Axel's hypothesis

Excitation modes built on excited states have the same properties as those built on the ground state.

$\rightarrow \mathcal{T}(E_\gamma)$ independent of excitation energy.

Factorization according to Fermis Golden rule

$$\mathbf{P}(\mathbf{E_i}, \mathbf{E}_\gamma) \propto \mathcal{T}(\mathbf{E}_\gamma)\rho(\mathbf{E_i} - \mathbf{E}_\gamma), \quad \text{where} \quad \mathbf{E_f} = \mathbf{E_i} - \mathbf{E}_\gamma \tag{1}$$

Least-squares method obtain $\rightarrow \mathcal{T}(E_\gamma)$ and $\rho(E_i - E_\gamma)$

$$\widetilde{\rho}(E_i - E_\gamma) = A \exp[\alpha(E_i - E_\gamma)]\, \rho(E_i - E_\gamma) \tag{2}$$

and

$$\widetilde{\mathcal{T}}(E_\gamma) = B \exp(\alpha\, E_\gamma)\, \mathcal{T}(E_\gamma), \tag{3}$$

Brink-Axel's hypothesis

Excitation modes built on excited states have the same properties as those built on the ground state.

$\rightarrow \mathcal{T}(E_\gamma)$ independent of excitation energy.

Factorization according to Fermis Golden rule

$$\mathbf{P}(\mathbf{E_i}, \mathbf{E}_\gamma) \propto \mathcal{T}(\mathbf{E}_\gamma)\rho(\mathbf{E_i} - \mathbf{E}_\gamma), \quad \text{where} \quad \mathbf{E_f} = \mathbf{E_i} - \mathbf{E}_\gamma \qquad (1)$$

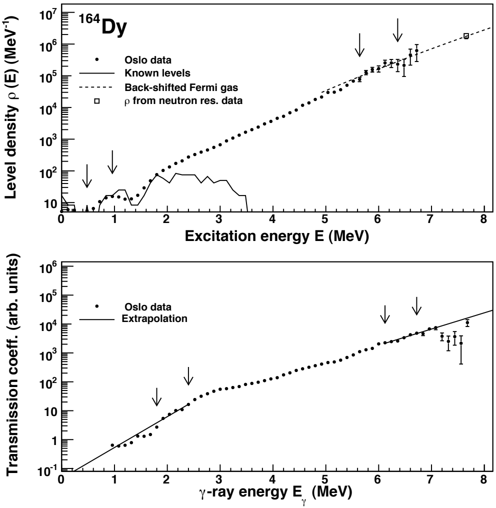
Least-squares method obtain $\rightarrow \mathcal{T}(E_\gamma)$ and $\rho(E_i - E_\gamma)$

$$\widetilde{\rho}(E_i - E_\gamma) = A \, \exp[\alpha(E_i - E_\gamma)] \, \rho(E_i - E_\gamma) \qquad (2)$$

and

$$\widetilde{\mathcal{T}}(E_\gamma) = B \, \exp(\alpha \, E_\gamma) \, \mathcal{T}(E_\gamma), \qquad (3)$$

Normalizing $\mathcal{T}(E_\gamma)$ and $\rho(E_i - E_\gamma)$



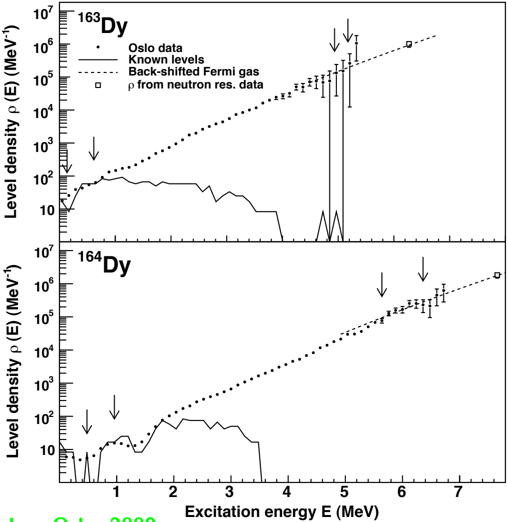
$\rho(E_i - E_\gamma)$:

- Known levels at low energy
- Neutron resonance data $\rightarrow$ extrapolated by the BS Fermi-gas model

$\mathcal{T}(E_\gamma)$:

- Calculated from average total radiative width $< \Gamma_\gamma >$

Experimental level density



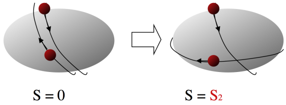
Breaking of nucleon-Cooper pairs

^{163} Dy

- $2\Delta_p = 1.32$ MeV

^{164} Dy

- $2\Delta_n = 1.66$ MeV
- $2\Delta_p = 1.75$ MeV



Micro-canonical ensemble

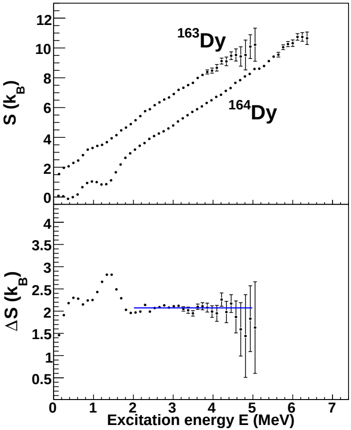
- Isolated system $\rightarrow$ the nuclear force has a short range and the nucleus does normally not share its excitation energy with its surrounding.
- Partition function given by the multiplicity of states,

$$\Omega_s(E) \propto \rho(E)(2(J(< E >) + 1)) \quad (4)$$

- The spin-distribution is not known, define a multiplicity of states which depends only of $\rho(E)$,

$$\Omega(E) = \frac{\rho(E)}{\rho_0} \quad (5)$$

Micro-canonical entropy

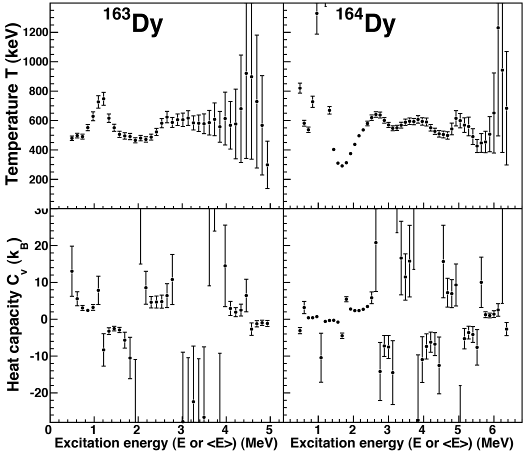


$$S = k_B \Omega(E) = k_B \ln \rho(E) + S_0. \quad (6)$$

Extensive quantity with respect to the number of quasi particles,

$$S = nS_1, \quad S_1 \approx 2.1 \; k_B \quad (7)$$

Micro-canonical results

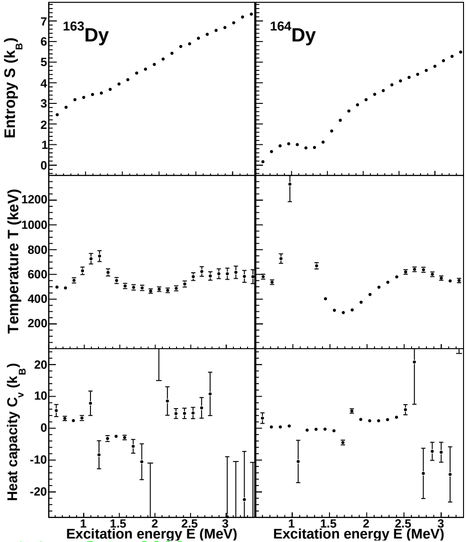


$$T = \left(\frac{\delta S}{\delta E}\right)_V^{-1} \quad (8)$$

$$C_v = \left(\frac{\delta T}{\delta E}\right)_V \quad (9)$$

Negative heat capacities $\rightarrow$ indicates breaking of pairs

Micro-canonical results



$$T = \left(\frac{\delta S}{\delta E}\right)_V^{-1} \qquad (10)$$

$$C_v = \left(\frac{\delta T}{\delta E}\right)_V \qquad (11)$$

Negative heat capacities $\rightarrow$ indicates breaking of pairs

Predicted γ-ray strength function

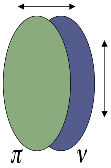
$$\mathbf{f} = \kappa(\mathbf{f_{E1}} + \mathbf{f_{M1}}) + \mathbf{f_{py}} \tag{12}$$

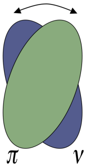
The KMF-model,

$$f_{E1}^{KMF}(E_\gamma, T_f) = \frac{1}{3\pi^2\hbar^2c^2}\frac{0.7\sigma E_\gamma \Gamma^2(E_\gamma^2 + 4\pi^2 T_f^2)}{E(E_{\gamma^2} - E^2)^2} \tag{13}$$

Lorentzian function

$$f_{M1,py} = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma E_\gamma \Gamma^2}{(E_\gamma^2 - E^2)^2 + E_\gamma^2\Gamma^2} \tag{14}$$





Predicted γ-ray strength function

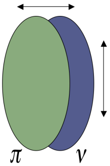
$$\mathbf{f} = \kappa(\mathbf{f_{E1}} + \mathbf{f_{M1}}) + \mathbf{f_{py}} \tag{12}$$

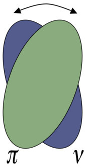
The KMF-model,

$$f_{E1}^{KMF}(E_\gamma, T_f) = \frac{1}{3\pi^2\hbar^2 c^2} \frac{0.7\sigma E_\gamma \Gamma^2 (E_\gamma^2 + 4\pi^2 T_f^2)}{E(E_{\gamma^2} - E^2)^2} \tag{13}$$

Lorentzian function

$$f_{M1,py} = \frac{1}{3\pi^2\hbar^2 c^2} \frac{\sigma E_\gamma \Gamma^2}{(E_\gamma^2 - E^2)^2 + E_\gamma^2 \Gamma^2} \tag{14}$$





Predicted γ-ray strength function

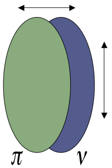
$$\mathbf{f} = \kappa(\mathbf{f_{E1}} + \mathbf{f_{M1}}) + \mathbf{f_{py}} \tag{12}$$

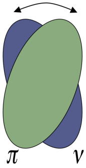
The KMF-model,

$$f_{E1}^{KMF}(E_\gamma, T_f) = \frac{1}{3\pi^2\hbar^2c^2}\frac{0.7\sigma E_\gamma \Gamma^2(E_\gamma^2 + 4\pi^2 T_f^2)}{E(E_{\gamma^2} - E^2)^2} \tag{13}$$

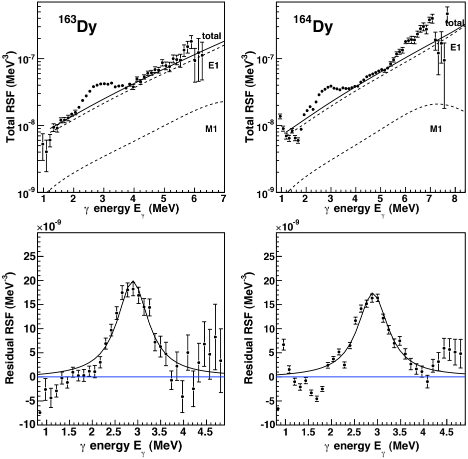
Lorentzian function

$$f_{M1,py} = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma E_\gamma \Gamma^2}{(E_\gamma^2 - E^2)^2 + E_\gamma^2\Gamma^2} \tag{14}$$





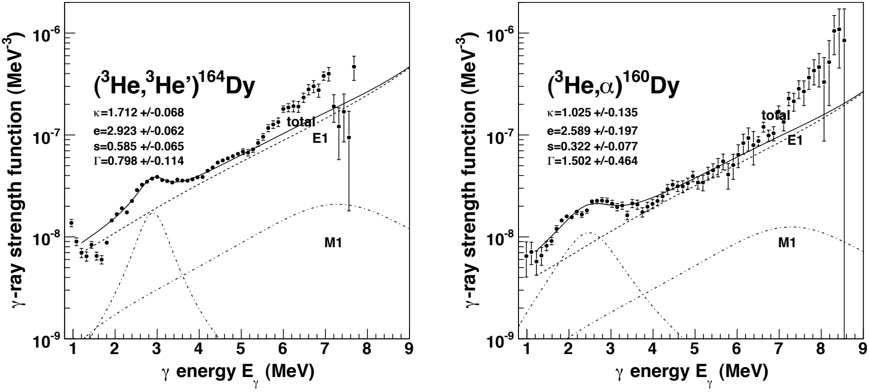
Experimental γ-ray strength function



Nucleus	E_{py} (MeV)	σ_{py} (mb)	Γ_{py} (MeV)	κ
^{163}Dy	2.92(12)	0.67(14)	0.82(22)	1.92(16)
^{164}Dy	2.92(06)	0.59(0.6)	0.80(11)	1.71(07)

Experimental γ-ray strength function

We see an unpredicted high strength for high energy γ-rays



Summary

- We measure a width of the pygmy resonance in a region between what is previously found in Oslo and what is measured in Prague
- The level density and thermodynamic properties displays characteristic features seen in other rare earth isotopes
- The γ-ray strength function displays an unpredicted high strength for high energy γ-rays

Summary

Collaborators

- University of Oslo: S. Siem, M. Guttormsen, A.-C. Larsen, A. Bürger, N. U. H. Syed, H. K. Toft, G. M. Tveten
- Ohio University, USA: A. Voinov

Thank you for listening...