SOFT RESONANCES IN HOT NUCLEI*

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The pygmy resonance at 3.3(1) MeV in ^{172}Yb has now been established with a strength of $B(\mathrm{M1}) = 6.5(15)\mu_N^2$ and M1 multipolarity. In addition, a strong unexpected enhancement of the radiative strength function has been found at low γ-ray energy in medium light Fe nuclei and also in the heavier Mo nuclei.

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1. Introduction

The nuclear level densities and radiative strength functions (RSF) are important input parameters in large network calculations of stellar evolution. These quantities have been studied for a wide range of nuclei. The experiments were carried out at the Oslo Cyclotron Laboratory, using the (^{3}He,α) and (^{3}He,^{3}He')-reactions with the 45 MeV ^{3}He-beam delivered by the MC-35 cyclotron. Charged particles and γ-rays were recorded with the multi-detector system CACTUS, which includes a NaI γ-detector array with a total efficiency of ~ 15 %. The Oslo group has developed a technique [1] to

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measure with high precision the level density and radiative strength function simultaneously in one and the same experiment. In this paper the focus is on the radiative strength function.

2. The multipolarity and strength of the pygmy resonance

A pygmy resonance at around 3 MeV has been observed in the RSF of several rare earth nuclei, see data points in left panel of Fig. 1. The solid lines are fits to the data based on models. The model of Kadmenskiĭ, Markushev, and Furman [2] is adopted to account for the E1 radiation, f_{E1}, and the M1 radiation f_{M1} is described by a Lorentzian based on the existence of a giant magnetic dipole resonance [3]. A pygmy resonance is also described with a Lorentzian function f_{py}, where a pygmy-resonance strength σ_{py}, width Γ_{py} and centroid E_{py} have been fitted in order to adjust the total theoretical strength function $f = K(f_{\mathrm{E1}} + f_{\mathrm{M1}}) + f_{\mathrm{py}}$ to the experimental data. For details of the equations and parameters used see Refs. [3–5].

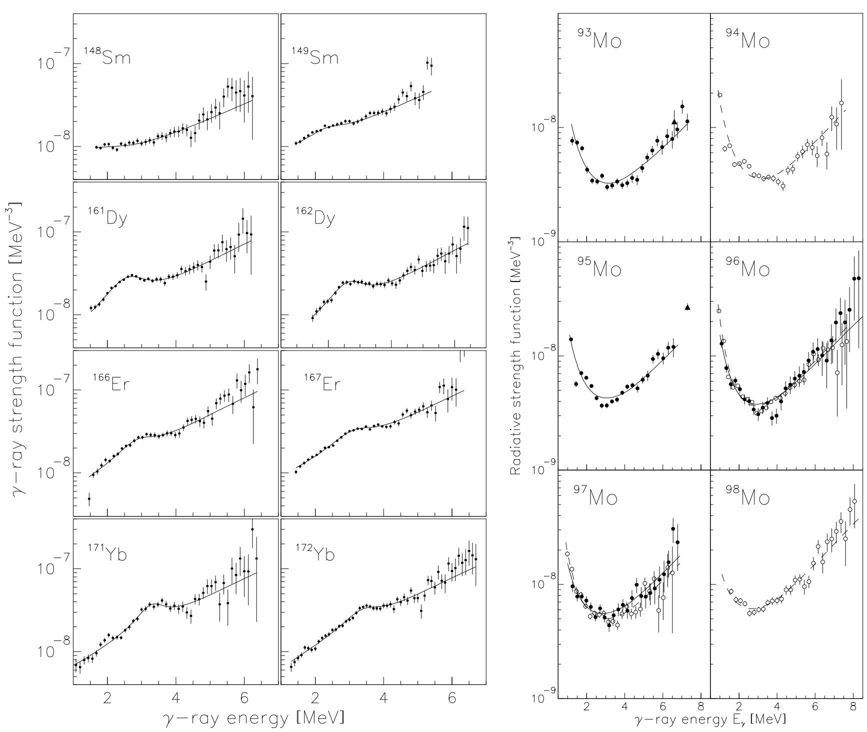

Fig. 1. Normalized RSFs for ^{148,149}Sm , ^{161,162}Dy, ^{166,167}Er, ^{171,172}Yb (left panel) and $^{93-98}$Mo (right panel). The circles are the experimental data. In the right panel the filled and open circles are data from the (^{3}He,α) and (^{3}He,^{3}He') reactions, respectively. The solid and dashed lines are fits to the respective reactions.

The pygmy resonance we observe is most pronounced in the well deformed ^{161,162}Dy, ^{166,167}Er and ^{171,172}Yb nuclei and less obvious in the almost spherical ^{148,149}Sm nuclei [4]. This is expected if this pygmy resonance is the scissors mode (deformed shapes of protons and neutrons oscillating like blades of scissors) which is deformation dependent. To determine the multipolarity of the observed pygmy resonance two-step cascade (TSC) spectra from the ^{171}Yb(n,$\gamma\gamma$)^{172}Yb reaction have been measured using thermal neutrons at the Lujan Center of the Los Alamos Neutron Science Center. They are compared to calculations based on experimental values of the level density and RSF obtained from the ^{173}Yb(^{3}He,$\alpha\gamma$)^{172}Yb reaction and M1 multipolarity has now been clearly established [6]. This is in agreement with Ref. [7], which also found evidence of the M1 multipolarity of the pygmy resonance in ^{163}Dy. The strength of this pygmy resonance is determined from the Oslo-type experiment using the expression: $B(M1)\uparrow = \frac{\sigma_{\rm py}\Gamma_{\rm py}}{E_{\rm py}}\frac{9\hbar c}{32\pi^2}$. The obtained value of 6.5(15) μ_N^2 is in agreement with the sum-rule approach for soft, orbital M1 strength [8] but is more than twice the strength reported from nuclear resonance fluorescence experiments [9]. Several explanations for this difference are discussed in Refs. [10–12].

3. Large enhancement of radiative strength at low E_γ

Recently, a strong enhancement of the RSF has been found at low γ-ray energies in medium light Fe nuclei [13] and also in the Mo nuclei [14] shown in Fig. 2 and right panel of Fig. 1, respectively. An enhancement of more than a factor of 10 over common theoretical models is observed for the soft ($E_\gamma < 2$ MeV) RSF of several Fe and Mo isotopes for transitions in the quasicontinuum (several MeV above the yrast line). To ensure that the observed enhancement is not connected to particularities of the nuclear reaction or analysis method, a TSC measurement based on thermal neutron capture has been performed. The TSC experiment, *i.e.*, the ^{56}Fe(n,2γ)^{57}Fe reaction, was performed at the dual-use cold-neutron beam facility of the Budapest Research Reactor. Details of the experiment and analysis are given in Ref. [13]. It confirms the findings from the Oslo experiments.

In conclusion, the pygmy resonance at 3.3(1) MeV in ^{172}Yb has now been established with a B(M1)$\uparrow$ strength of 6.5(15)μ_N^2 and M1 multipolarity [6]. And an enhancement of more than a factor of 10 of soft transition strength (a soft pole) in the total RSF of Fe and Mo isotopes is observed. This enhancement cannot be explained by any present theoretical model and is an exciting challenge to be solved.

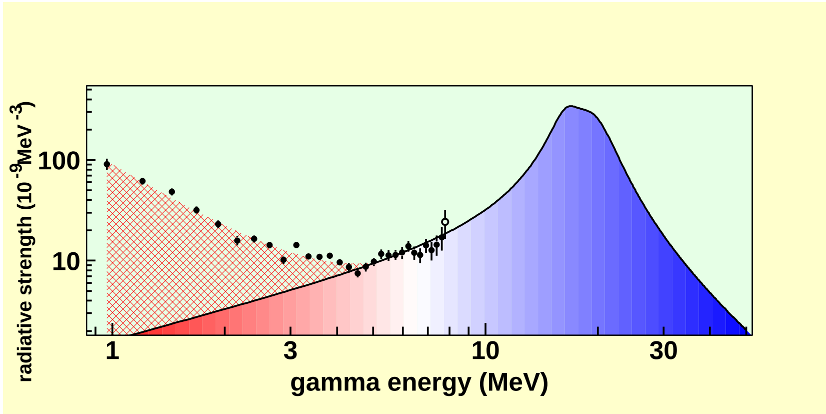

Fig. 2. Data points: The experimental radiative strength function(RSF) for ^{57}Fe. Open circle: Lowest previous data point from literature. Solid line: A standard nuclear theory prediction (Lorentzian) for the tail of the GEDR. Hatched area: Excess yield of low-energy radiation.

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