

नाभिकीय अभिक्रिया

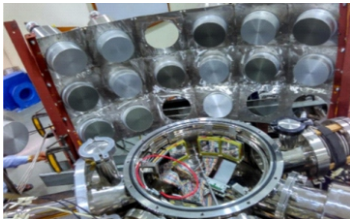
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नाभिकीय-स्तर घनत्व का अध्ययन

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Si पट्टिका संसूचक सरणी द्वारा आवेशित कण का पता लगाने के साथ-साथ तरल सिंटिलेटर संसूचक सरणी का उपयोग करके न्यूट्रॉन स्पेक्ट्रा के विशेष माप हेतु प्रयोगात्मक व्यवस्था।

सारांश

न्यूट्रॉन वाष्पीकरण स्पेक्ट्रा के एक विशेष माप के माध्यम से नाभिकीय स्तर घनत्व की सामूहिक वृद्धि और विकृत ^{171}Yb , ^{161}Dy में उत्तेजन ऊर्जा के साथ इसके धूमिल होने की स्थिति का पता लगाया गया। ^{169}Tm और ^{159}Tb पर ^7Li -प्रेरित अभिक्रिया में एक ट्राइटन के स्थानांतरण के माध्यम से ^{172}Yb एवं ^{162}Dy नाभिक की बहुसंख्यता प्राप्त की गई। न्यूट्रॉन स्पेक्ट्रा के सांख्यिकीय मॉडल विश्लेषण ने सूक्ष्म गणनाओं के अनुरूप 42 ± 2 के एक बड़े सामूहिक वृद्धि कारक को उजागर किया। मैक्सवेलियन औसत न्यूट्रॉन प्रग्रहण अनुप्रस्थ काट को समझने में मापित परमाणु स्तर घनत्व का एक बड़ा प्रभाव पाया गया।

Nuclear Reactions

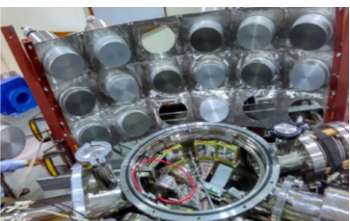
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Study of Nuclear-level Density

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The experimental set-up for exclusive measurement of neutron spectra using liquid scintillator detector array along with charged particle detection by Si strip detector array.

ABSTRACT

The collective enhancement of nuclear level density and its fade-out with excitation energy in the deformed ^{171}Yb , ^{161}Dy , obtained through an exclusive measurement of neutron evaporation spectra. The ^{172}Yb and ^{162}Dy nuclei were populated via the transfer of a triton in a ^7Li -induced reaction on ^{169}Tm and ^{159}Tb . Statistical model analysis of the neutron spectra revealed a large collective enhancement factor of 42 ± 2 , consistent with microscopic calculations. The measured nuclear level densities were found to have a huge implication in the understanding of the Maxwellian Averaged Neutron Capture cross section.

KEYWORDS: Nuclear-level density, Radiative neutron capture, Neutron evaporation spectra, Shell effect, Shell damping factor

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Introduction

The nuclear level density (NLD) is a fundamental property of the nuclei. It is defined as the number of nuclear energy levels per unit excitation energy (E^*), and increases rapidly with E^* . The NLD is a crucial input in statistical model calculations of compound nuclear decay. It is also required in the study of fission hindrance in heavy nuclei, the giant dipole resonance built on excited states, the yields of evaporation residues in fusion evaporation reactions, production of heavy elements in stellar processes etc. Due to the liquid drop like properties of the nucleus, the NLD is expected to have a smooth behavior with respect to the mass (A) and atomic number (Z). However, this behavior is modified by the excitation energy dependent nuclear shell effects. Deformed nuclei are found to have a larger NLD compared to their spherical counterparts. In our lab we have studied various aspects of the NLD.

Shell Effect on Nuclear Level Density and its Damping with Excitation Energy near Pb Region

The nuclear level density makes a transition from the shell-dominated regime at low excitation energy to that of a classical liquid drop at high excitation. The shell effect is disappeared at high excitation energy (~ 40 MeV) and its implication to fission fragment anisotropy has been predicted by Ramamurthy, Kapoor and Kataria in 1970 [1]. The damping of the nuclear shell effect with excitation energy has been measured, using the experimental setup as shown in Fig.1, through an analysis of the neutron spectra following the triton transfer in the ^7Li induced reaction on ^{205}Tl . The measured neutron spectra demonstrate the expected large shell correction energy for the nuclei in the vicinity of doubly magic ^{208}Pb and a small value around ^{184}W . A quantitative extraction of the allowed values of the damping parameter (γ), along with those for the asymptotic nuclear level density parameter ($a=A/\delta a$), has been made for the first time [2]. The measured damping factor was extracted from the data and found to be $\gamma=0.06^{+0.01}_{-0.02} \text{ MeV}^{-1}$. (see Fig. 2).

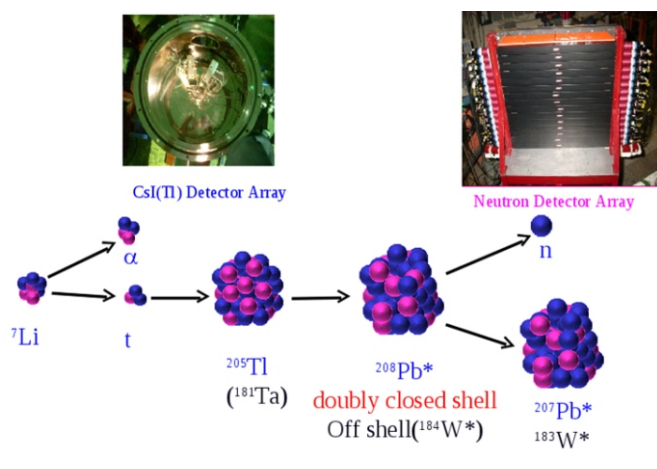


Fig.1: Experimental set-up for exclusive measurement of neutron spectra using $\sim 1 \text{ m}^2$ plastic scintillator array.

Collective Enhancement of Nuclear Level Density

The occurrence of collective rotational motion implies an increase in the degrees of freedom available for low E^* and thus a significant increase in the NLD. The collective enhancement of the nuclear level density is predicted to be damped out with excitation energy. The exclusive measurements of neutron spectra following alpha particle emission in $^{11}\text{B}+^{181}\text{Ta}$, ^{197}Au systems [3] forming compound nuclei ^{192}Pt and ^{208}Po respectively have been carried out at the PLF, Mumbai. An array of 15 liquid scintillators (two inch thick and 5 inch diameter) was used for fast neutron measurement and two telescope consisting of Si-strip detectors were used for the measurement of alpha particle by energy loss technique. The inverse level density parameter k ($=\delta a$) as a function of excitation energy of the residual nucleus has been extracted by fitting the neutron spectra with statistical model calculation (see Fig.3). Statistical model calculations were performed considering an enhancement level density $\rho_{\text{int}} K_{\text{coll}}$ where ρ_{int} is intrinsic level density and K_{coll} is the enhancement factor. K_{coll} as a function of excitation energy (or temperature) was obtained and extracted value of critical temperature where collective enhancement vanishes agrees well with the theoretically predicted value.

Experimental Evidence of Large Collective Enhancement of Level Density and its Significance in Radiative Neutron Capture

In the continuation of the NLD program, two more measurements on nuclear level density have been carried out for nuclei with mass $A \sim 170$. The collective enhancement of nuclear level density and its fade out with excitation energy in

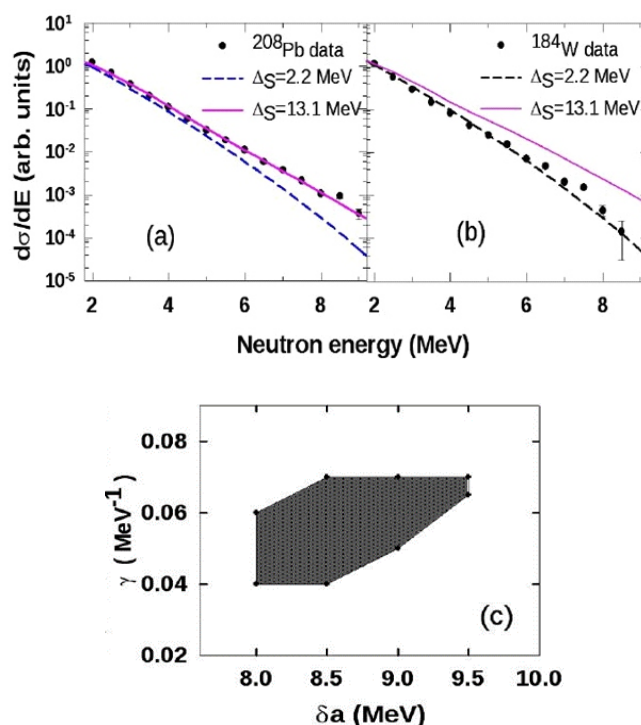


Fig.2: (a, b) Effect of shell correction on neutron spectra from ^{208}Pb and ^{184}W , (c) Exclusion plot between level density parameter and shell damping factor [2].

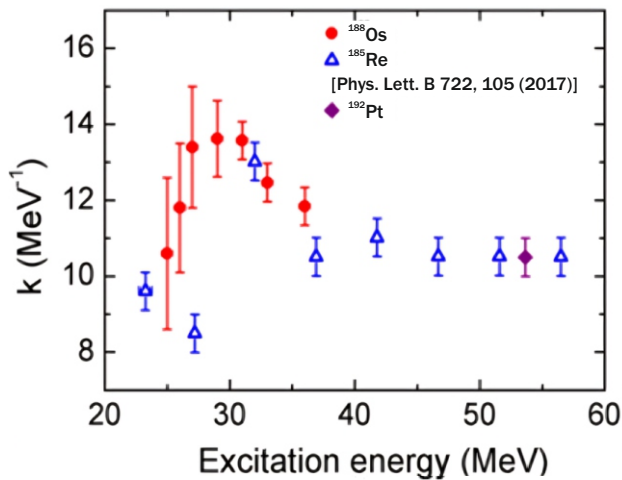


Fig.3: Inverse level density parameter as a function of the excitation energy of the nuclei.

the deformed ^{171}Yb and ^{161}Dy nuclei have been inferred through exclusive measurements of neutron spectra. These two nuclei were populated via the stripping transfer of a triton in a ^7Li -induced reaction on ^{169}Tm and ^{159}Tb respectively. The statistical model analysis of neutron spectra demonstrated large collective enhancement factors of 40 ± 3 and 42 ± 2 respectively [4,5], consistent with recent microscopic model predictions but very different from the existing measurements for the nearby deformed nuclei. This is the largest collective enhancement factor obtained from the measurements and reported in any system to date. A fade-out in the enhancement has been observed at the energy of 14 ± 1 MeV. The complete form of energy dependent collective enhancement was experimentally deduced for the first time by combining the measured NLD with the Oslo data as shown in Fig. 4.

The neutron-capture process is responsible for the formation of the heavy nuclei between iron and the actinides [6]. In order to find the implication of large collective enhancement, we have calculated the Maxwellian average neutron capture cross section (MACS) at 30 KeV for ^{171}Yb and ^{170}Yb . The MACS at 30 KeV were calculated using our measured NLD given as input in the TALYS code. This is achieved by incorporating our collective enhancement form into the TALYS-1.96 reaction code [7].

The level density of the Fermi gas model with the measured collective enhancement was used to calculate the MACS and then compared to KADoNIS-v1 [8] and estimation of Bao et al. [9] for both ^{171}Yb and ^{170}Yb , as shown in Fig.5(a) and (b), respectively. To see the effect of collective enhancement on MACS, various TALYS calculations with different collective enhancement factors have been performed. Fig.5 shows the MACS calculated using TALYS with the enhancement factor 40 and the reported enhancement factor 10 in nearby mass region. The default gamma-ray strength function (gSF), the Simplified Modified Lorentzian (SMLO, strength 9) and default optical model potential parameters [10] were used in the calculation. It's important to note that even with different

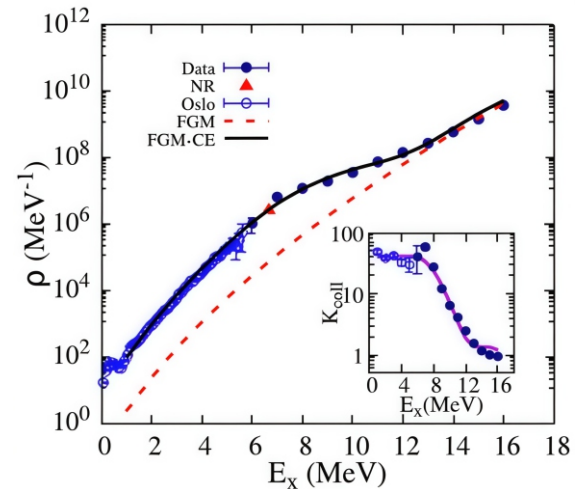


Fig.4: The NLD obtained as a function of excitation energy using Oslo data (open circles) [34] and present experiment (filled circles), normalized to the level density at the neutron resonance point (NR) (triangle). The dashed red line shows intrinsic level density from fermi gas model (FGM) and black solid line shows fermi gas level density with collective enhancement (FGM-CE), both obtained using CASCADE with the level density formulae described in the text. The inset shows collective enhancement with excitation energy obtained from the combined data sets.

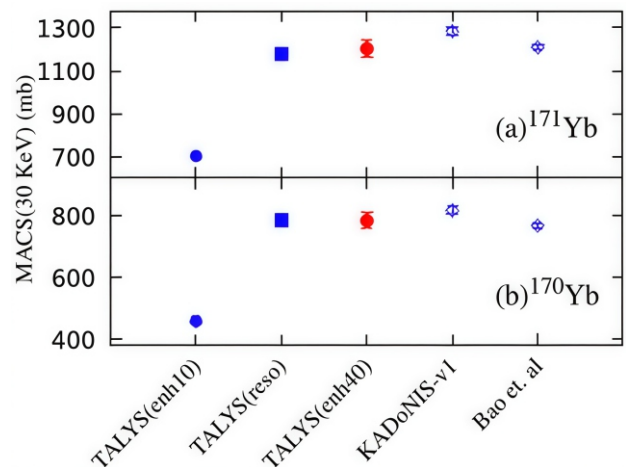


Fig.5: (a) Calculated MACS at 30 KeV for ^{171}Yb using the Talys-1.96 and its comparison with KADoNIS-v1 compilation, well-established Bao et al. estimation, (b) Same as (a) for ^{170}Yb . Here, TALYS(enh10) and TALYS(enh40) were using the present level density prescription with enhancement factor 10 and 40, respectively. TALYS(reso) was the calculated MACS using the measured level density at neutron resonance energy.

combinations of gSF and a collective enhancement factor of 40, the calculated values of MACS are similar to experimental values. However, using an enhancement factor of 10 showed significant differences from the experimental values. The predicted MACS using the present level density prescription, including the measured enhancement factor (TALYS(enh40)), agrees with the experimental MACS values, while the collective

enhancement factor 10 (TALYS(enh10)) could not be reproduced well. Therefore, in a statistical model, it is necessary to include the proper NLD prescription with collective enhancement, which significantly improves the predicted capture cross sections relevant for the astrophysical s-process.

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