Evidence for pairing reentrance in level density for $A \sim 100$ nuclei

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Introduction

In a series of measurements in the ^{12}C+^{93}Nb reaction at E(^{12}C)=40−45 MeV, the proton spectra, in coincidence with a γ−ray multiplicity detector array, showed broad structures (Fig. 1) on a monotonically falling spectrum, particularly, at the higher multiplicities [1–3]. The peak energy of the structures decreased with increasing γ−ray multiplicity and increased at the higher beam energy. The spectra could be fitted using the statistical model (SM), by multiplying the phenomenological nuclear level density (NLD) by an empirical factor which is dependent on the excitation energy (E_X) and angular momentum (J) and given by :

$$\varepsilon(E_X, J) = 1 + Kf(E_X)g(J),$$

with

$$f(E_X) = \begin{cases} exp\left[-\frac{(U-E_c)^2}{2\sigma_X^2}\right] & \text{if} \quad U > E_c \\ 1 & \text{if} \quad U < E_c \end{cases}$$

where $U = E_X - E_{Rot} - \Delta_P$ and

$$g(J) = \begin{cases} exp\left[-\frac{(J-J_c)^2}{2\sigma_J^2}\right] & \text{if} \quad J < J_c \\ 1 & \text{if} \quad J > J_c. \end{cases}$$

Here E_{Rot} is the yrast energy which depends on J and Δ_P is the pairing energy. The best fit values of the parameters are $K = 30$, $E_c =$ 3 MeV, $J_c = 18$ and σ_X & σ_J are 1.5 - $0.025J$ MeV and 1.3, respectively. Fig. 2 shows the variation of NLD with temperature T (which is related to the E_X) in ^{104}Pd, for a specific J.

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In order to gain insight into the origin of these structures, three additional measurements were carried out. (1) γ−ray multiplicity gated proton spectra were measured in coincidence with the characteristic low energy γ−rays [2] detected in the first implementation of the INGA using 8 HPGE clover detectors. This showed that the structures were not due to target impurities. (2)Proton spectra were measured in ^{12}C+^{93}Nb and ^{16}O+^{89}Y channels populating the same compound nucleus (CN) ^{105}Ag. In both cases the spectra showed similar structures [3]. (3) A measurement at forward and backward angles ($\theta_{CM} \sim 90° \pm 35°$) was made to discriminate between the two likely emission mechanisms *viz.*, CN and massive transfer. The ratio of the energy differential center-of-mass cross sections was 0.9±0.2, as seen in Fig. 3, consistent with the CN mechanism for proton emission. The results of the last two measurements clearly indicate a CN origin of the structures thus implying a local modulation of the conventional NLD as a function of T at higher J.

The modulation of NLD with temperature due to the effect of pairing correlations at high spin was pointed out by Kammuri [5]. Shell model calculations performed with realistic effective interactions confirmed these conclusions [6]. Recently, a state-of-the-art calculation has been reported for ^{72}Ge using the shell model Monte Carlo approach [7]. This clearly demonstrates the effect of reentrance of pairing correlations with T at moderately high J. At a rotational frequency (ω) such that $\hbar\omega = 0.5$ MeV, the E_X dependence of NLD shows a kink at $T \sim 0.5$ MeV, while the behaviour is smooth for $\hbar\omega = 0.2$ MeV. It is interesting to note that the values of E_c and J_c in our enhanced NLD prescription for ^{104}Pd correspond to similar values (~ 0.5 MeV for T and $\hbar\omega$). The possibility of fitting the

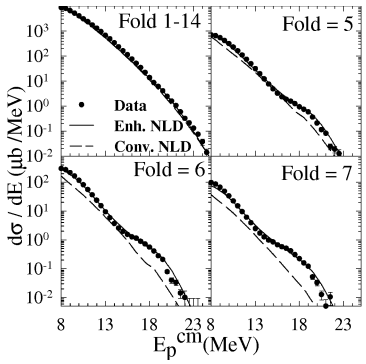

FIG. 1: $\gamma-$ray multiplicity gated proton spectra from ^{12}C+^{93}Nb reaction at E(^{12}C)=40 MeV [2].

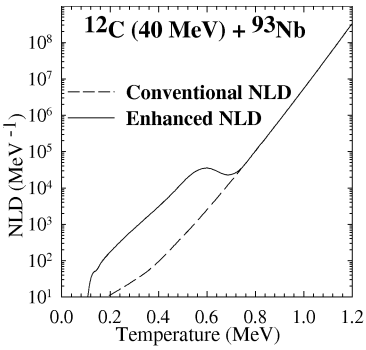

FIG. 2: Plot of NLD as a function of temperature at $J = 20$ in ^{104}Pd for the conventional and empirical prescriptions.

spectra with a Gaussian in E_X is being explored. Such an experimental observation of reentrant pairing correlation has not been recognized by us, nor to our knowledge, by the authors of Ref. [7]. If this is substantiated by theoretical calculations for $A \sim 100$ region, it will strengthen the observation that the pairing reentrance has been seen experimentally.

The phenomenon of reentrant pairing should manifest itself in various areas of high spin nuclear physics, where a moderate E_X region above the yrast line is encountered. The NLD prescription used in all the SM calculations should be modified. Besides changing the high-energy part of the particle spectra (as has been discussed here for protons), this should have an impact on the extracted E1 strength functions from heavy ion reactions, continuum $\gamma-$ rays from an excited nucleus below the particle emission threshold, population of high spin isomers etc.

Summary

In summary, we have related our earlier results on the (T, J) dependent enhanced NLD (deduced from the analysis of $\gamma-$ray multiplicity gated proton spectra) with the reentrant pairing correlation phenomenon. This was suggested long back and a rigorous calculation was presented only recently. To our knowledge, this is the first experimental demonstration of this interesting effect.

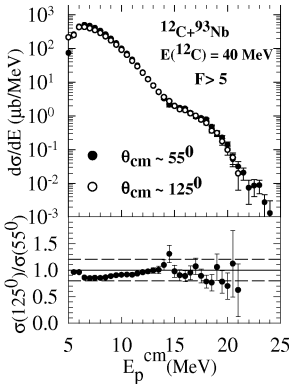

FIG. 3: Proton spectra from the ^{12}C+^{93}Nb reaction at E(^{12}C)=40 MeV at $\theta_{CM} \approx 55°$ and 125°.

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