Exploration of the Shell Effect on the Level Density Parameter near the Doubly Closed Shell Nucleus A∼208

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Shell effect is the manifestation of the finite fermionic systems such as atoms and nuclei. This plays an important role in describing the structure and the properties of the matter. The nuclei with closed nucleon shell, in analogy to the atomic shell structure, have a significantly greater stability with respect to the neighbouring nuclei. These nuclei are more stable than that predicted by the liquid drop model (LDM). There are many important nuclear phenomena such as the occurrence of super heavy elements fission isomers, superdeformed nuclei and new magic numbers in exotic nuclei which are the consequences of the shell effect. The shell effect also affects the nuclear level density (NLD). The NLD is defined as the number of energy levels per MeV at excitation energy (E_X). The dependence of the NLD on the excitation energy and angular momentum (J) was first derived by Bethe using Fermi gas model. The generic behaviour with respect to E_X is described by $e^{2\sqrt{aE_X}}$. Here 'a' is the NLD parameter which is related to the single particle density at the Fermi energy. The NLD is a fundamental property of the nucleus and a crucial input to the statistical calculation of compound nuclear decay. This is thus an important physical quantity for many practical applications, such as the calculations of reaction rates relevant to nuclear astrophysics, nuclear reactors and spallation neutron sources.

It has been inferred from various measurements that on an average the level density parameter a increases linearly with the mass number(A) of the nucleus as $a \approx$A/8 MeV^{-1}. This smooth behaviour with respect to mass is due to the liquid drop like properties of the nucleus. However, there is a significant departure from this liquid drop value at shell closures. This departure is the largest for the doubly magic nucleus ^{208}Pb, where the effective a is as low as A/26 MeV^{-1} at E_X ∼7 MeV. There is a long standing prediction that this shell effect on the NLD parameter is expected to wash out with excitation energy so that a approaches its liquid drop value at $E_X \geq 40$ MeV [1].

One possible method to populate ^{208}Pb at low excitation energy is the triton transfer in the ^{7}Li induced reaction on ^{205}Tl target and assumed that populated intermediate nucleus is in thermal equilibrium and decay as per statistical model of compound nuclear decay. We can then measure the neutron spectra from the excited ^{208}Pb nucleus in coincidence with the out-going alpha particles. Since the intrinsic efficiency of the neutron detector is very small, we require a large angular coverage for the neutron detectors and also need an efficient charged particle detector system for measurement of alpha particles. The thesis work includes the setting up a large area neutron detector array, development of CsI(Tl) detector array for α- particle detection and measurement of damping of shell effect in ^{208}Pb region.

Large Area Neutron Detector Array: We have set up a neutron detector array (∼ 1×1m^2) at the Mumbai Pelletron Linac Facility (PLF), which consists of 16 plastic scintillator bars of square cross section [2]. Each bar has a dimension 6 cm×6 cm×100 cm and is coupled to two 5 cm diameter XP2020 PMTs, one each at either end. The characterization of the plastic detector was done using radioactive sources and also for mono-energetic and continuum neutrons using beams from the

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PLF. The energy, time and position response has been measured for quasi-mono-energetic electrons using Compton tagging of scattered γ-rays and for mono-energetic neutrons using the ^{7}Li(p,n$_1$)^{7}Be*(0.429 MeV) reaction at proton energies between 6.3 and 19 MeV. The array has been used to measure the evaporation neutron spectrum in the reaction ^{12}C+ ^{93}Nb at E(^{12}C)= 40 MeV and the measured spectrum compares well with the statistical model calculation. A Monte Carlo simulation algorithm has been developed in-house to simulate the neutron energy dependent efficiency of the array. The Monte Carlo simulated efficiency of the plastic scintillators for the neutron detection agrees with that obtained from the ^{7}Li(p,n$_1$) measurements.

Detector Array for α-measurement:
An array of 8 CsI(Tl) detectors with active area of 2.5 cm $\times$ 2.5 cm and thickness of 1 cm has been assembled to detect the light charged particles with a reasonably large efficiency. The standard pulse shape discrimination method is used for the particle identification by measuring the zero cross over timing (ZCT) of the amplified bipolar pulse . The energy response of the CsI(Tl) detectors to α-particles has been measured from 5-25 MeV using a ^{229}Th source and the ^{12}C(^{12}C, α) reaction at E(^{12}C) = 24 MeV populating discrete states in ^{20}Ne. The energy non-linearity and the count rate effect on the PSD property has also been measured and it was found that the PSD deteriorates for count rate $\geq$3 kHz.

The question pertaining to the shell effect and its damping with excitation energy in the double closed shell nucleus ^{208}Pb can be addressed using these two detector arrays. The exclusive neutron spectra from ^{208}Pb have been measured in coincidence with ejectile alpha particles. The nucleus ^{208}Pb, formed in the excitation energy range 19 - 23 MeV, decays predominately by the neutron emission populating the residual nucleus in the $E_X \sim$ 3 - 14 MeV. Over this E_X range, the NLD parameter is expected to show a significant change due to the damping of the shell effect. We have also made a control measurement with a ^{181}Ta target populating nuclei in the ^{184}W region where the shell effect is expected to be small. The statistical model(SM) analysis of 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. Furthermore, the detailed analysis of the neutron spectra from ^{208}Pb in various excitation energies within the frame work of statistical model of compound nuclear decay using the phenomenological NLD prescription [3], the damping parameter (γ) and asymptotic level density parameter($\tilde{a}$) were constrained for a fixed shell correction energy. The shell correction energy was taken as 13.1 and 11.7 MeV for ^{207}Pb and ^{206}Pb, respectively. An exclusion plot between the damping parameter and the inverse level density parameter δa (= A/$\tilde{a}$) has been made for the first time. It is observed that the acceptable range of δa lies between 8.0 and 9.5 MeV. The parameter γ controlling the damping of the shell effect can be constrained to $(0.060^{+.010}_{-.020})$ MeV^{-1} [4]. This is different from the value extracted from the neutron resonance data *viz*. (0.079 $\pm$ 0.007) MeV^{-1} [5].

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