Level density and shape evolution of unstable doubly magic ^{24}O

S. Santhosh Kumar[1],* and P. Preetha[2]
[1]Department of Physics, Avvaiyar Govt. College for Women, Karaikal-609602, U.T.of Puducherry, INDIA
[2]Research Department of Physics, Bharathiyar University, Coimbatore-606060, Tamil Nadu, INDIA
* email: santhosh.physics@gmail.com

Introduction

The oxygen isotopes are the heaviest nuclei for which the neutron drip line has been experimentally well established[1], of which isotopes up to ^{24}O lies within the drip line, since beyond N=16, the neutron separation energy became negative. It is the first doubly magic nucleus with one conventional magic number(p=8) and an unconventional magic number(n=16). The understanding of such neutron rich environment help us to study neutron stars and supernovae. An important feature in the shell structure is the presence of gaps in the single-particle spectra and which provides an understanding of the system in terms of the interaction between nucleons. It is known that the energy of the first excited 2^+ state is one of the indicators for magic nuclei and a sharp rise is observed in the energy value of the 2^+ excited state at N=16. The neutron separation energy for N=16 is reported as 3.6MeV and it gives a negative separation energy for one neutron addition. The lower limit of 3.6 MeV for a bound excited state implies a doubly magic property[2].

Most of the existing experimental data are based on measuring level densities at an energy close to the neutron binding energy, by counting the number of neutron resonances observed in low energy neutron capture. The level densities can be determined at lower excitation energies by directly counting the observed excited states. At present the level density for practical applications is calculated mainly on the basis of Fermi gas and Gilbert-Cameron formulae with adjustable parameters which are found from experimental data on neutron resonance spacing and the density of low lying discrete levels. In GDR studies, particularly damping width have been studied in several nuclei for excitation energy ranging from 50-200MeV, and it has been shown that the analysis of experimental data is very sensitive to the dependence of level density on excitation energy[3]. The current knowledge of the drip line is limited to only the lightest nuclei and it was established for oxygen in 1997[4].

Theoretical Approach

The present work is to extend the Monte Carlo method of actual counting [5] of complexions or configurations that yield the same energy E and spin J of the whole nucleus containing N_o available states for the n particles in the system. For light nuclei, this method is more realistic provided shell model and single particle levels incorporating proper parameters are used. The results presented here indeed reflect the shift in the most probable energy and spin in a system when the entropy S, energy E and spin J, surface is drawn. It should be noted that these spins are purely due to single particle excitation, not collective excitation. The method starts with the generation of single particle states ε_i as a function of z component of the single particle spins m_i say up to N=11 shells using the Nilsson model with Lund parameters, κ and μ for the sake of simplicity. The single particle eigenvalues ε_i are different for protons and neutrons (ε_i^Z and εi^N). The diagonalisation of the Hamiltonian is done using cylindrical basis states with Hill-Wheeler deformation parameters (θ,δ).

The particles, neutrons/protons, are allowed to fill up the states in a random fashion. Suppose in the K^{th} configuration if n_{iK} is the single particle occupation probability then the total particle number n is, $n = \Sigma\, n_{iK}$, the corresponding total energy for the K^{th} configuration $E = E_K = \Sigma\, n_{iK}\varepsilon_i$. Here K is the index for configurations and 'i' represent single particle levels. The different configurations generated in the N_o particle states by n number of particles ($N_o \geq n$) for a given J and E are then counted to get the total number of configurations W(E,J) for each J and E [6]. The entropy S(E,J) are then obtained using the equation, S(E,J) = k ln W(E,J), where k is the Boltzman constant.

Result and Discussion

The binding energy for $^{26,24,22}O$ is calculated using the Droplet model and we obtained a maximum value for ^{26}O with a difference of 1.3MeV from ^{24}O, and ^{24}O is 3.8MeV from ^{22}O. Such a higher binding energy difference from the neighbouring lower mass even nuclei provides the extra stability to ^{24}O eventhough its deformation is comparatively high, which is the first evidence for its magicity.

A prolate (at $J = 0\hbar$; γ=-120°) to oblate deformed (at $J \geq 4\hbar$; γ=-180°) shape change via spherical (δ=0.0)is observed for ^{24}O, since W_{max} shifts from prolate to spherical and then to oblate. The maximum probable state of ^{24}O is prolate deformed (γ=-120°; δ=0.5), since the W_{max} obtained of(J=1$\hbar$) is the maximum , ie., W_{max} = 2.274320x10^6. The maximum probable state W_{max} at J=0 is at the excitation energy 67.44Mev, at Ω=0.0$\hbar\omega$ with W_{max}= 1.494129x10^6(δ=0.5,) which is less than the superdeformed shape (δ=0.6) and hence the possibility of fission is very less. Hence it is expected to be an unstable doubly magic nucleus. Our calculations reveal that at J=3$\hbar$, ^{24}O behaves like a spherical one (δ=0.0) with W_{max}=2.222676x10^6 at 67.44MeV energy and from J=5$\hbar$, it is oblate with decreasing deformation. The most probable macroscopic state will correspond to the peak marked as W_{max} in 3D graph (fig.1) and may reflect e^{Smax} in experimental observations.

The level density or entropy is maximum (S_{max}=6.3568515) at J=1$\hbar$ (prolate) when Ω = 0.0$\hbar\omega$. From the level density we retrieve the level density parameter as usual from the equation, $\rho = \exp(2(aE^*)^{1/2})$, where a is the level density parameter and E^* is the excitation energy. The level density parameter is calculated according to the equation $a=S^2/4E^*$, and is plotted against spin(fig.2), which shows a smooth Gaussian. The small drip in level density parameter at J=3$\hbar$ indicates the shape transition from prolate to spherical. From J=5$\hbar$, it is very smooth and is oblate in shape. Since the level density is an important function in astro-physical studies, this result may be highly useful in astrophysics.

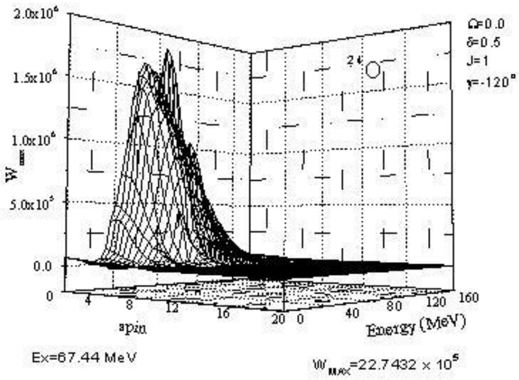

Fig. 1 3-dimensional plot of the most probable microscopic state (spin in the units of $\hbar$).

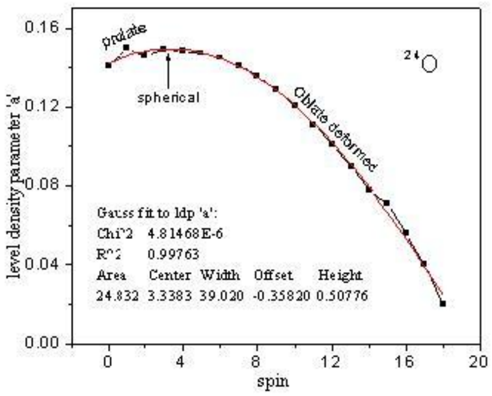

Fig. 2 The ldp 'a'(MeV^{-1}) against spin ($\hbar$). Data given inside are for Gaussian fit.

References

[1] S.C.Pieper, et al., Phys. Rev. C66, 044310 (2002).
[2] B.A.Brown & W.A.Richter, Phys. Rev. C72, 057301 (2005).
[3] A.Bracco et al., Phys. Rev. Lett. 62, 2080 (1989).
[4] T.Baumann et al., Nature, 449, 1022 (2007).
[5] F. C. Williams Jr.,et al., Nucl. Phys. **A187**, 225 (1972).
[6] S. Santhosh Kumar, Pramana J. phys. 71, 175 (2008).