Excitation energy dependence of shell effects on nuclear level densities

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Introduction

It is now well known that the deviation of the single particle states from a uniform distribution results in a shell correction energy to the liquid drop model value of the nuclear mass. The ground state shell correction energies have been calculated by well known macroscopic-microscopic formulations. In an earlier work, Ramamurthy *et al.* [1] have calculated the excitation energy dependence of the nuclear entropy S (which determines the nuclear level densities for the excited nucleus) starting from the single particle states for a modified spherical harmonic potential with parameters of Seeger and Perisho [2]. Fig.1 shows the results of this calculations for two typical cases of doubly closed shell ^{208}Pb with shell correction energy Δ_{shell} (defined as difference between experimental mass of the nucleus and its liquid drop mass) of -9.2 MeV and for spherical shape ^{242}Pu with Δ_{shell} of 14.5 MeV .

It was concluded in this earlier paper that a relation of the form $S^2=4a(E_x+\Delta E_x)$ can be used, in general, for the calculation of the nuclear entropy. The term ΔE_x was shown to vary with excitation energy such that it becomes equal to the Δ_{shell} at higher excitation energy as shown by intercepts on energy axis by asymptotic dotted lines in Fig. 1and equal to zero at the zero excitation energy. This shows that the shell effects are wiped out with excitation energy and at this higher excitation energy, the entropy can be calculated by the simple formula of $S^2=4aE_x$ provided E_x is measured from the liquid drop ground state energy as shown in Fig. 1 . In other words, this amounts to shifting of the excitation energy by an amount which varies from 0 to Δ_{shell} as excitation energy is increased. However, in this earlier work, S^2 vs Ex curve was not fitted to an empirical formula to give a generalized relationship to take into account the damping of shell effects with excitation energy.

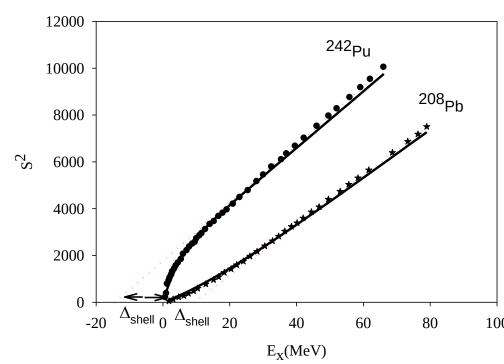

Fig. 1 S^2 vs Excitation energy calculations from Ref. 1. The continuous curves are fits to Eq. 1. Red dotted lines show asymptotic behavior at higher energies in each case.

In a similar calculation carried out later by Ignatyuk *et al*. [3], the S^2 vs Ex curve was fitted with an empirical relation of the form

$$S^2 = 4a(E_x+\Delta_{shell}(1-\exp(-\gamma E_x))) \qquad [1]$$

In fitting the results of various nuclei, the damping factor γ was taken to be the same irrespective of sign and magnitude of shell correction and was determined to be 0.054.

This formula has since been extensively used in various statistical model codes for the level densities.

Results and Discussions

We have now carried out least square fits using Eq. 1 to the earlier calculations of Ref. 1 on the excitation energy dependence of nuclear entropy for two typical cases of nuclei having a negative (-9.2 MeV) and a positive (14.5 MeV) shell correction corresponding to doubly closed shell ^{208}Pb and spherical shape ^{242}Pu respectively for level density parameter, 'a' = A/8 MeV^{-1} .

For the case of negative shell correction of ^{208}Pb, we find the value of γ=0.0541 from the fits which is in agreement with the value given by Ignatyuk. This agreement is indeed remarkable as Ignatyuk's calculations reproduce the earlier calculations of Ramamurthy *et al.* [1]. The fit is shown in Fig. 1 as continuous curve. The variation of ΔE_x with E_x for this case is shown in Fig. 2 as dashed curve.

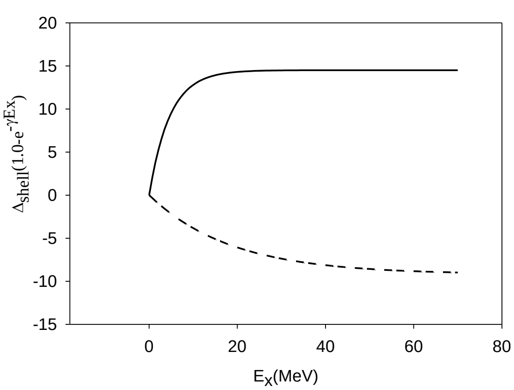

Fig. 2 ΔE_x vs Ex for ^{208}Pb (Dashed) and ^{242}Pu (Continuous)

But for the case of spherical shape of ^{242}Pu, where shell correction is positive, the value of γ is found to be 0.213 which is very different from the case of ^{208}Pb with negative shell correction energy. The fits for this case is shown in Fig. 1 as continuous curve. The variation of ΔE_x with E_x for this case is shown in Fig. 2 as continuous curve.

These results, as shown in Fig. 2, indicate much faster damping of the shell effects with excitation energy for the case of positive shell correction energy as compared to the case of negative shell correction energy. This implies that damping factor γ depends on both magnitude and sign of shell correction energy and more calculations should be carried out to see the exact dependence of γ on the Δ_{shell}. This result may have implications on the statistical model calculations of the actinide nuclei with double humped barriers and for super-heavy nuclei as the Igantyuk's value of γ may not be valid to calculate the shell damping with excitation energy for the case of positive shell correction cases at fission barrier.

References

[1] V.S. Ramamurthy, S.S. Kapoor and S.K. Kataria, PRL **25,** 386 (1970)

[2] P.A. Seeger and R.C. Perisho, Los Alamos Scientific Laboratory Report No. LA-3751, 1967

[3] A.V. Ignatyuk, G.N. Smirenkin and A.S. Tishin,, Sov. J. Nucl. Phys. **21**, 255 (1975)