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${}^{146}_{64}\mathrm{Gd}_{82}$, a doubly magic nucleus

P. Mukherjee, R. Bhattacharya, and I. Mukherjee
Saha Institute of Nuclear Physics, Calcutta-700 009, India

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Single proton and neutron states are extrapolated from the recently revised shell model states of ^{208}Pb with the help of optimized Woods-Saxon potentials. A proton magic gap of 2.3 MeV at $Z = 64$ and a neutron magic gap of 4.5 MeV at $N = 82$ are established at mass number $A = 146$.

[NUCLEAR STRUCTURE ^{146}Gd, estimates of proton and neutron shell gaps.]

Recent experimental investigation[1-4] on the level schemes of nuclei around ^{146}Gd strongly favored the occurrence of a good magic gap at $Z=64$, making ^{146}Gd a good doubly magic nucleus. The empirical shell model approach, which works so well in the ^{208}Pb region,[5] has also been effectively used in the ^{146}Gd region. A large number of theoretical efforts are being made[6-9] to examine the magicity at $Z=64$. Some of these theoretical studies[7,8] are based on the self-consistent approach, but they have been unable to provide clear evidence for a shell closure at $Z=64$. While such a many body approach is of fundamental importance in understanding the single particle spectra, they give[10,11] only a qualitative fit with the observed single particle spectra. Moreover, the existence of the magic gap at $Z=64$ depends crucially on the reliable evaluation of the $1h_{11/2}$ proton state in ^{208}Pb and the rate of change of the binding energy of this state with decreasing mass number. A many body approach is known[12] to be inadequate to account for the movements of these high spin intruder states. The alternative approach of estimating the single particle binding energies with a Woods-Saxon potential is meaningful only when the parameters of this potential are carefully evaluated and a reliable method of extrapolation is used. In a recent work[13] we proposed that the parameters of the Woods-Saxon potential for ^{208}Pb be optimized with respect to the revised single particle states in ^{208}Pb, taking into account the observed fragmentations of many of these states.[14] We feel that any extrapolation of the shell model states, either towards the superheavy region[13] or towards the lower mass region, should be done starting from ^{208}Pb, since the dynamics of fragmentation of the shell model states is well understood for this nucleus and all the shell model states are known here.

TABLE I. Woods-Saxon potential parameters for ^{208}Pb.

	V_0	r_0	a_0	V_s	r_s	a_s
Neutron	42.479	1.310	0.718	24.312	1.246	0.391
Proton	64.620	1.184	0.640	32.510	1.136	0.785

The Woods-Saxon potential parameters, as optimized with respect to the revised shell model states of ^{208}Pb, are listed in Table I. In order to examine the shell model states in the lower mass region we change the depth of the potential according to the following equations:

$$V_n = \left(V_{0n} - K_n \frac{N-Z}{A}\right) f_n(r)\,,$$

$$V_p = \left(V_{0p} + K_p \frac{N-Z}{A}\right) f_p(p)\,.$$

K_n and K_p are separately adjusted to 33.0 MeV to reproduce the known neutron states in the $N=82$ nuclei of Ce, Nd, and Sm, and the proton states of the $Z=50$ nucleus Sn. The majority of the states in ^{208}Pb are reproduced within 200 keV with the potentials of Table I. For the $1i_{13/2}$ state the discrepancy is about 700 keV. This will give an indication of the accuracy of the level schemes.

The results of the extrapolation of the shell model states are shown in Figs. 1 and 2. In the proton spectra we find a pronounced gap at $Z=64$ in the mass region $A=140$ to 150. The magnitude of this gap (2.3 MeV), together with the pairing energy, is consistent with the 3.38 MeV gap in Ref. 1. The proton spectra agree very well with the level spacings obtained from the analysis of ^{145}Eu spectra.[7] It is interesting to note that the magic gap at $Z=64$ rapidly vanishes as we go through the rare earth region. From Fig. 2 we note that the neutron magic gap at $N=82$ is 4.5 MeV for $A=146$, and is thus considerably larger than the corresponding proton gap at $Z=64$. We, therefore, conclude that the low lying states in ^{146}Gd are proton particle hole states. This is an unique feature, since for all other doubly closed shell nuclei the proton and the

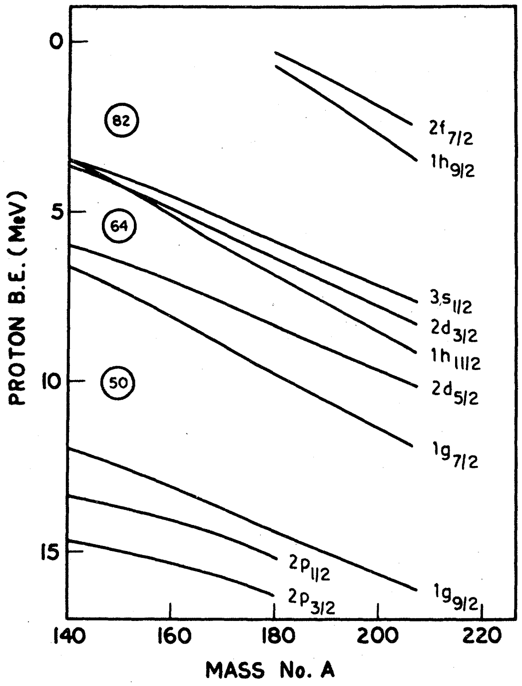

FIG. 1. Proton single particle states in the region A =140–208.

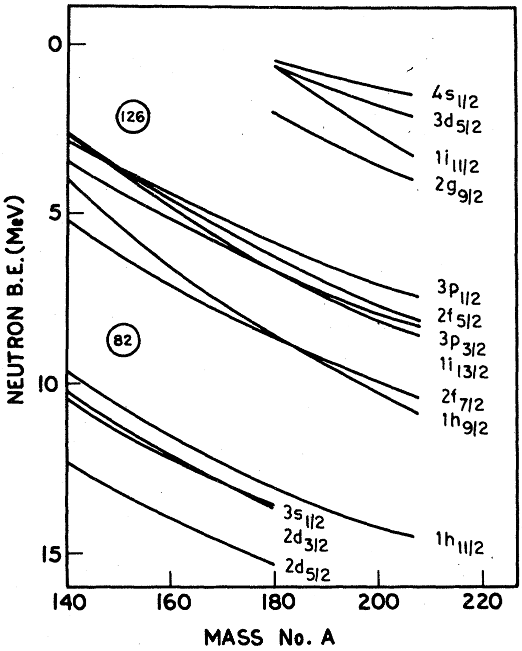

FIG. 2. Neutron single particle states in the region A =140–208.

neutron magic gaps are of comparable magnitude. Another important finding of the present work is the occurence of the $1i_{13/2}$ neutron state at a considerably larger excitation energy in the mass region $A \sim 150$ (Fig. 2). The development of the high spin yrast states in this region will be hindered because of the higher excitation energy of the $1i_{13/2}$ neutron state.

To conclude, we have been able to demonstrate in this work a smooth transition of the shell model states from the extensively studied ^{208}Pb region to the new region of the doubly closed shell nucleus ^{146}Gd. A good proton magic gap exists for ^{146}Gd, but the gap is considerably smaller than the neutron gap. The proton gap at $Z = 64$ rapidly vanishes as the mass number is increased, making the beginning and the end of the rare earth region somewhat different structurally.

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