Magicity from Proton Separation Energies

C. Anu Radha* and E. James Jebaseelan Samuel
School of Advanced Sciences, VIT University, Vellore - 632014, INDIA
**canuradha@vit.ac.in*

Introduction

The origin of the unusual stability of nuclei with nucleon numbers 2, 8, 20, 28, 50, 82 and 126, commonly referred to as “magic numbers”, was explained more than half a century ago to be due to nuclear shell structure. The discovery in 1984 that similar magic numbers also appear in small clusters of lighter elements was at first surprising since the nature of force holding atomic clusters and nuclei are fundamentally different. In analogy with the stability of magic nuclei, the magic numbers in alpha clusters were explained due to electronic shell closure.

Recently there is a proliferation of new magic or rather quasi-magic numbers. At the same time some magic numbers are demoted and seem to lose their magicity. In the simple shell model these are due to shell or sub-shell closures. Shell closure may be demonstrated by a large drop in separation energies. Such phenomena can be simply explained by the simple shell model. The single- and two-nucleon separation energies are fundamental properties of the atomic nucleus. It is a challenge for nuclear many-body theories to derive the shell model simplicity out of the complexity of their calculations. The fact that all single- and two-nucleon separation energies show a similar *N/Z* dependence suggests an underlying physical reason for this dependence. It is well-known that separation energies of isotopic and isotonic nuclei of a given parity type (even–even, even–odd, odd–even, or odd–odd) follow linear systematic within each shell region if plotted against *N* and Z.

Systematic of proton and neutron separation energies can be powerful tools to study the nuclear structure at and even beyond the drip lines. It can be used to predict masses and separation energies of nuclei beyond the neutron and proton drip lines. Single proton and two proton separation energies show a big drop beyond ^{20}Ca. It can be said that for Z=8, N=14 is a quasi-magic number.

Work formalism

Separation energies for neutron number N and for proton number Z fixed separately at 6 to 22 in steps of 2 [1, 2]. For example Fig.1 and Fig 2 are respectively plots of S_{1p} for fixed N= 3, 6, 10, 11, 12, 16, 18, 20 and 22 plotted as a function of Z and for fixed Z = 3, 6, 10, 11, 12, 16, 18, 20 and 22 plotted as a function of N. After various comparisons it may be shown that new magic numbers appear and some others disappear in moving from stable to exotic nuclei in a rather novel manner due to a particular part of the nucleon-nucleon interaction [3]. In summary, we have shown that all single- and two-nucleon separation energies exhibit a similar *N/Z* behavior.

Nuclei near the proton drip line

Besides the appearance of new shell closures, the conventional shell closures at $N = 8$ and $N = 20$ were on the other hand found to disappear in neutron-rich nuclei.

A strong kink has been observed in the lower magic numbers across N = 8 and N = 20 (vertical dotted lines in Fig.2) is clearly a measure of shell gaps at the magic numbers. Thus the shell gaps provide a sensitive observable for the shell effects in nuclei. Hence we focus upon Sp and S2p values to explore the nature of shell effects.

When adding protons, asymmetry and Coulomb term reduce the binding therefore steeper drop of proton separation energy - drip line reached much sooner.

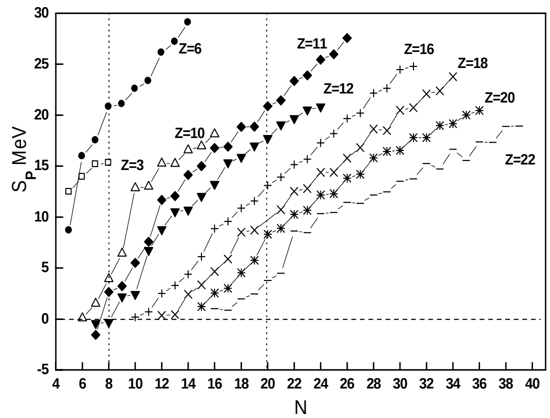

Fig. 1 Separation energy Vs Z for various N values

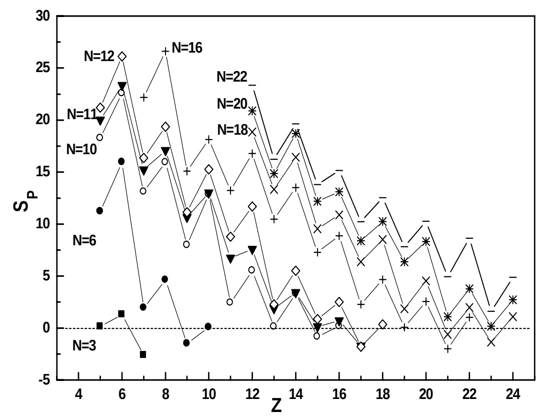

Fig. 2 Separation energy Vs N for various Z values

Two-proton separation energies exhibit jumps when crossing magic proton numbers. The magnitude of the jump is a measure of the proton magic shell gap for a given neutron number [4].

It is shown that separation energies disclose rich nuclear structure information. They indicate very clearly the major shell closures at $P = P_{magic}$ or $N=N_{magic}$ reflected by strong discontinuities of S_p, S_{2p}, S_n and S_{2n} as a function of Z and N. The evolution of nuclear collectivity is reflected as a smooth variation of separation energy as a function of N or Z. First of all, it shows exactly where are the neutron subshell closures and its dependence of the proton number; if the major proton spherical shell closures do not influence the two neutron separation energies, the proton subshell closures due to their nature (proton-neutron interaction) are reflected in the behavior of Separation energies.

Another effect which is due to the proton-neutron interaction, the critical point of the transition from spherical to deformed shapes, is reflected in the variation of Separation energies but the effect is small and is visible only in the evolution of the derivative of S_{2p} as function of neutron or proton number. The two proton separation energies and their evolution with neutron and proton number constitute a very good starting point in testing various nuclear structure models. The analysis presented in this paper shows the need of very precise data on masses and extension of this type of information to nuclei very far from stability. We are in the process of extending such a study.

References

[1] G.Audi, A.H.Wapsta and C.Thibault, Nucl.Phys. A729 (2003) 337.
[2] G.Shanmugam, C. Anu Radha and V.Ramasubramanian, DAE Symp. on Nucl.Phys. 46B (2003) 310.
[3] A.Abbas, Mod. Phys.Lett. A16 (2001) 755.
[4] C.Anu Radha, M.Phil. Thesis (2005) 97.