# Alpha decay Q-value as a probe to study shell evolution

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## Introduction

For the last two decades, there have been ample experimental results of evidence to show that the "magic numbers" of nuclear structure which assured extra stability may change as one moves away from the valley of nuclear stability.

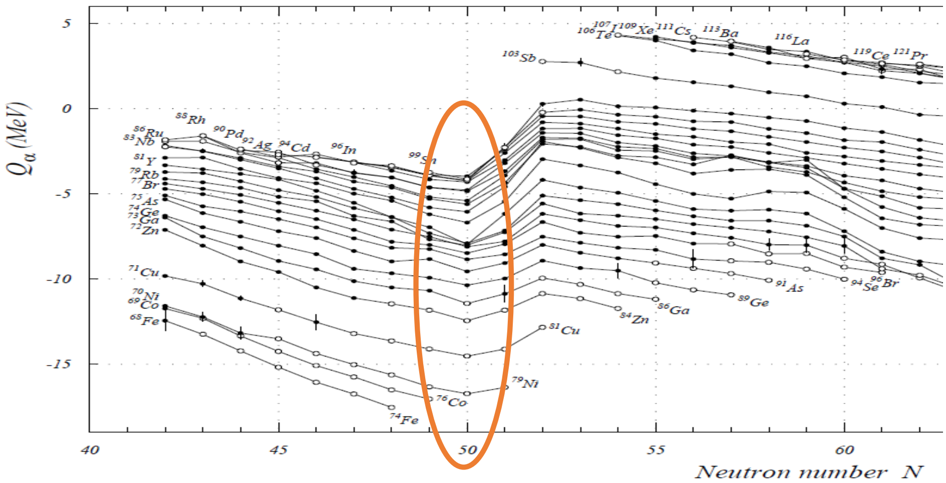


**Fig. 1** Variation of Q value of alpha decay for various elements around N=50. A clear dip at N=50 is observed for all elements as highlighted in the figure. The figure is taken from http://amdc.impcas.ac.cn/masstables/Ame2016/graphs2016/filel.html. Similar plots for other neutron magic numbers can be found there.

Apart from the excitation energy of the first excited state and its transition probability, mass filters like single neutron separation energy ($S_n$), two neutron separation energy ($S_{2n}$) are used to identify these "extra-stable" numbers. Alpha decay Q value ($Q_\alpha$), has been used as another common indicator to study the stability of heavy and super-heavy nuclei, where alpha decay has been one of the primary modes of decay. However, in the present work we want to demonstrate the importance of this mass index to study the evolution of shell structure throughout the nuclear landscape, even in the region where alpha decay is not even a valid mode of decay.
If the variation of alpha Q value is plotted as a function of neutron numbers for different isotopic chains, a clear dip in the Q value is observed at the magic numbers (Fig.1). However, it is also evident that even for a specific magic neutron number, the dip is not equally deep for all elements. Inspired by this observation from the standard literature, we wanted to study systematically this variation in the depth of the dip as a function of atomic number for a specific neutron magic number.

## Methodology

The differences

$$\Delta Q_\alpha = Q_\alpha(N\_magic+2,Z) - Q_\alpha(N\_magic,Z), \quad \ldots\ldots (1)$$

have been evaluated for various elements using the 2016 Mass data [1]. It is noted that the $Q_\alpha$ may be positive or negative depending on the mass region. For several nuclei, they are negative as alpha decay is not a favored mode.

## Results and Discussion

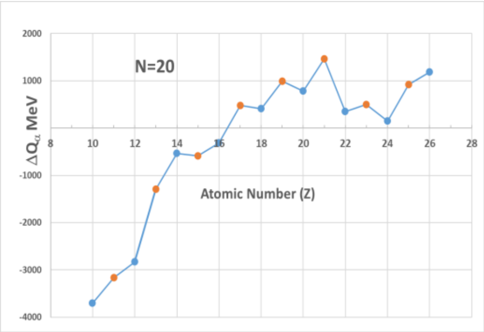


**Fig.2** The variation of Q value difference for N=20.

Thus, the sign of the differences along with its magnitude is also important for understanding. Let us now systematically analyze the plots for specific magic numbers one by one.

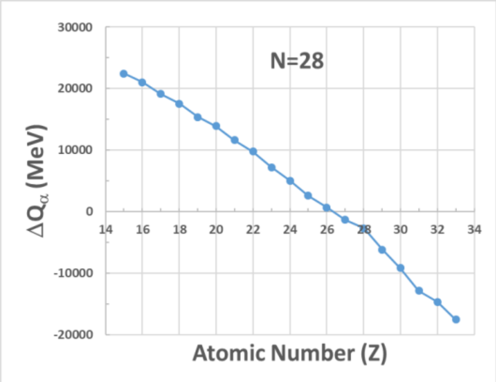


**Fig.3** The variation of Q value difference for N=28.

- For N=20, all the Q values are negative. Thus. negative $\Delta Q_\alpha$ for Z<17 indicates that for those elements, the Q value of the isotope with (Magic no+2) neutrons is more negative than that of the isotope with magic neutron number, indicating absence of a dip or minimum at N=20. However, for Z>16, the dip prevails and the magicity of N=20 persists. Moreover, the peak of the plot is at Ca, which is a doubly magic nucleus for N=20 indicating the most stable N=20 nucleus.
- The other interesting feature in the plot is the odd-even staggering of the differences. Whether the lower $\Delta Q_\alpha$ for even Z nuclei above Z=16 indicate possibility of alpha clustering needs more detailed analysis.
- The Fig. 3 for N=28 is almost featureless, devoid of the odd-even staggering. For Z>26, the nuclei become more proton-rich with N=28, thus stability reduces and effect of magicity too.
- For N=50 and 82, all the differences are positive and thus indicate the robustness of the magic numbers with the most stable combinations being with Z~40 and Z~50, respectively, indicated by peaks in the plots.
- However, staggering is observed N=50 for a limited region in contrast to the N=82 plot.

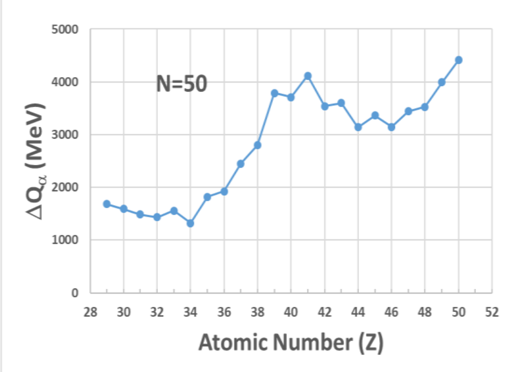


**Fig.4** The variation of Q value difference for N=50.

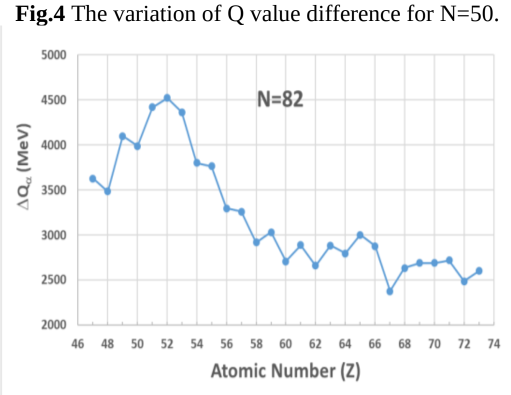


**Fig.5** The variation of Q value difference for N=82.

The preliminary analysis of the results indicates very interesting possibilities of exploiting this mass filter for studying shell evolution in atomic nuclei. They can be also utilized as a sensitive indicator to study alpha clustering.

## Acknowledgments

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## References

1. ATOMIC MASS DATA CENTER: http://amdc.impcas.ac.cn/web/masseval.html