Finding Most Stable Isobar for Nuclides with Mass Number (165- 175) against Beta Decay

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Abstract

In the beta decay process, a neutron converts into a proton, or vice versa, so the atom in this process changes to a more stable isobar. Bethe-Weizsäcker used a quasi-experimental formula in the present study to find the most stable isobar for isobaric groups of mass nuclides (A=165-175).

In a group of isobars, there are two methods of calculating the most stable isobar. The most stable isobar represents the lowest parabola value by calculating the binding energy value (B.E) for each nuclide in this family, and then drawing these binding energy values as a function of the atomic number (Z) in order to obtain the mass parabolas, the second method is by calculating the atomic number value of the most stable isobar (Z_A).

The results show that the mass parabolas of isobar elements with an even mass number (A=even) vary from the mass parabolas of isobar elements with an odd mass number (A=odd), In the case of single isobars, it has one parabola, meaning that it has one stable isobar, while we find that the pairs isobars appear to have two parabolas, meaning that it has more than one stable isobar. When we compared the two methods used in this study to determine the most stable isobars, we found that in two techniques for odd isobars, stable isobars are mostly the same nuclide, whereas in suitcases of even isobars with two stable isobars (only one of them are same stable isobars).

Key Words: Binding Energy, Liquid Drop Model (LDM), Bethe-Weizsäcker Semi Empirical Formula, Mass Parabolas, Isobaric Nuclides.

DOI Number: 10.14704/nq.2021.19.4.NQ21032 **NeuroQuantology 2021; 19(4):15-19**

Introduction

The nuclide refers to an nucleus distinguish by the number of neutrons (N) and protons (Z) that the nucleus consist of (Junlong Tian, *et al*, 2017).

Isobars are nuclei of the same amount of atomic mass (A), but there is a distinction between the atomic number (Z). There is an instance of a pair of isobars:

$$_1H^3 \ \& \ _2He^3$$

Isobaric nucleus displays the projecting portion of beta decay and electron capture (Murtadha S. Nayyef and Naz T. Jarallah, 2020).

Beta particles (β) are electrons that are charged negatively or positively (e- & e+). The atomic number (Z) increases by one unit in the case of (β-) decay. But the atomic number (Z) will be reduced by one unit in the case of (β+) decay. By taking an atomic electron, generally from the K shell, and releasing a neutrino and reducing the atomic number (Z) by one unit, several nuclei move through a radioactive transition. (James E. Turner, 2007).

Theoretical Part

Several authors have established isobaric decay of β-decay energies (M. Nageshwari, 2014, M.K. Preethi Rajan, *et al*, 2017, Ankita and B. Suthar, 2016).

M. Nageshwari this study gives a notional account of beta decay stabilization for the isobaric family against mass parabolas. In Ref. (M.K. Preethi Rajan, *et al*, 2017) M.K. Preethi Rajan.et al.

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 08 February 2021 **Accepted:** 10 March 2021

Sophisticate an equation to finding the more stable isobar for a given mass number versus beta decay. They have also studied the mass parabola for several isobars with mass number extend from (200-223). It was found that the minimum point in the parabola, which is the Z value of most stable isobar versus β decay, agree with our prognosis.
Ankita and B. Suthar in Ref. (Ankita and B. Suthar, 2016). Using the semi-experimental formula, nuclear binding energies were calculated using different constants given by different researchers. The nuclear binding energies were calculated using the semi-empirical formula using different constants provided by different researchers, then compared these measurements with the experimental values measured and then applied this comparison analysis to the calculation.
Physicists working in the field of nuclear physics have been working hard for many years to provide a simple and complete nuclear model in which nuclear properties are explained and understood. Current successful nuclear models can only explain specific properties of the nucleus, but they cannot make comments about other nuclear properties. For example Liquid Drop Model (LDM) was presented by Von Weizsacker and then was extended by Bohr and Wheeler.
This model gives the nuclear binding energy equation in terms of A and Z as follow (Ghahramany N., *et al*, 2013).

$$B.E(A,Z) = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_a\ (A-2Z)^2\ A^{-1} \pm \delta A^{-1/2}\ + \eta \qquad (1)$$

Where: a_v, a_s, a_c, a_a, δ and η are the energy constants that represent to the volume, surface, Coulomb, asymmetry, pairing and shell energy terms, respectively (Norman, D, Cook., 2010).
One set of this factors is (Norman, D, Cook., 2010):
a_v=15.8Mev, a_s=18.3Mev, a_c=0.72Mev, a_a=23.2MeV.

$$\text{And } \delta = \begin{cases} +11.2 \text{ MeV for (even N, even Z)}. \\ 0 \text{ for (even N odd Z, or even Z, odd N)}. \\ -11.2 \text{ MeV for (odd N, odd Z)}. \end{cases}$$

And

$$\eta = \begin{cases} 3 \text{ Mev (N and Z = magic number)}. \\ 2 \text{ Mev (N or Z = magic number and other is odd)}. \\ 1 \text{ Mev (N or Z = magic number and other is even)}. \\ 0 \text{ (N or Z = no magic number)}. \end{cases}$$

The liquid droplet model (LDM) succeeded in calculating both more stable isobars, binding energies, and mass parabolas, but at the same time it failed to predict other nuclear properties such as magic numbers and nuclear magnetic moments (Ghahramany N., et al, 2013).

Applications of Bethe– Weizsäcker formula

Mass Parabola

A Bethe-Weizsäcker semi-empirical formula is used to determine the most stable isobar of a assumed mass number (A) against beta decay by plotting the binding energy as a function of the atomic number(Z) (M.K. Preethi Rajan, *et al*, 2017).
The mass parabolas of the different isobars fall in two groups according to the mass number of the isobar either odd or even (M.K. Preethi Rajan, *et al*, 2017). The isobars placed on the sides of the parabola unstable, so these nuclides will be decay to be more stable and lower on the parabola (Tian, J., *et al*, 2017).
Isobars possessing an atomic number ($Z > Z_A$) can decay by emitting positive Beta (β^+) and neutrino (ν) or electron capture (EC). While the isobars that possessing an atomic number ($Z < Z_A$) can decay by emitting negative beta (β^-) and antineutrino (ν^-) (Cottingham, WN., *et al*, 2001).

Atomic Numbers for most Stable Isobar (Z_A) Value

We can now define, for each isobaric family, the nuclide of isobar with the lowest mass (largest binding energy) which represents the most stable isobar, by solving the equation 16

$$\frac{\partial}{\partial Z}\text{(B.E (Z,A))} = 0, \qquad (2)$$

So the atomic number (Z_A) value for most stable isobar can be taken by:

$$Z_A = \frac{A}{2\left(1+\frac{1}{4}\left(\frac{a_c}{a_a}\right)A^{\frac{2}{3}}\right)} = Z_A = \frac{A}{2(\,1 + 0.0077A^{\frac{2}{3}})} \qquad (3)$$

(Kris Heyde, “Basic,2004)

Results and Discussion

The findings of this study will be described and discussed in depth, while the objective of this study is to classify the most stable isobar for isobaric families with mass number (A) equal to (165-175). Two different methods have been used to evaluate the most stable isobar for isobars under this study:

Determined the most Stable Isobar from Mass Parabola

Mass parabolas for nuclides with mass number (A= 165-175) are obtained by plotted binding energy (B.E) ranging from (1323651-1349102) MeV as a function to atomic number (Z). This binding energy

(B.E) value is determined by means of the Weisscker semi-empirical formula eq. So we're having mass parabolas with various isobars. As seen in the figures, mass parabolas for an odd and even mass number (A are drawn separately (1&2).

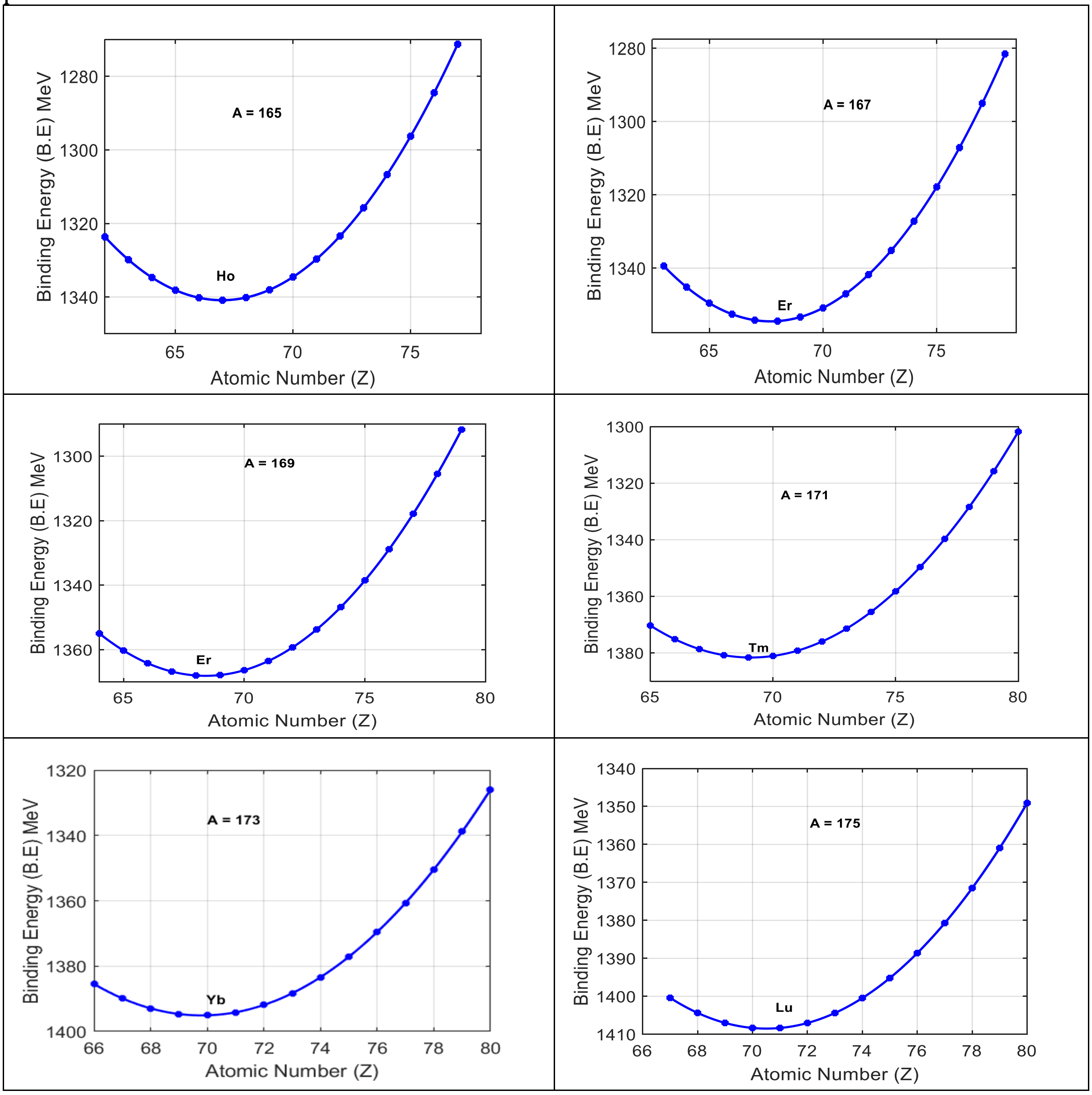
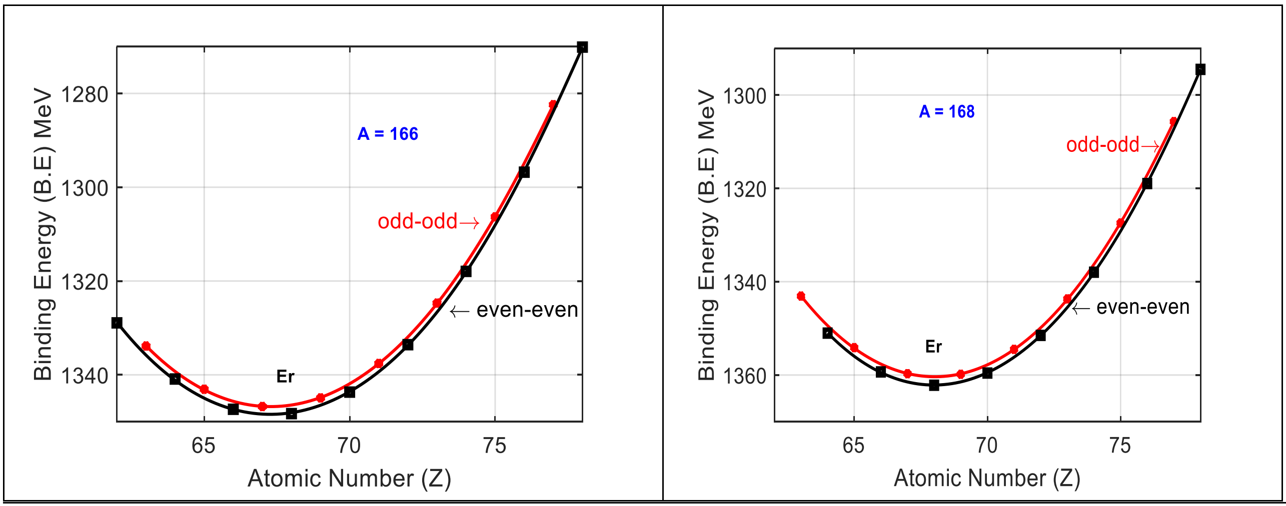


Figure 1. Mass parabolas for isobars with odd mass number (A=165-175)



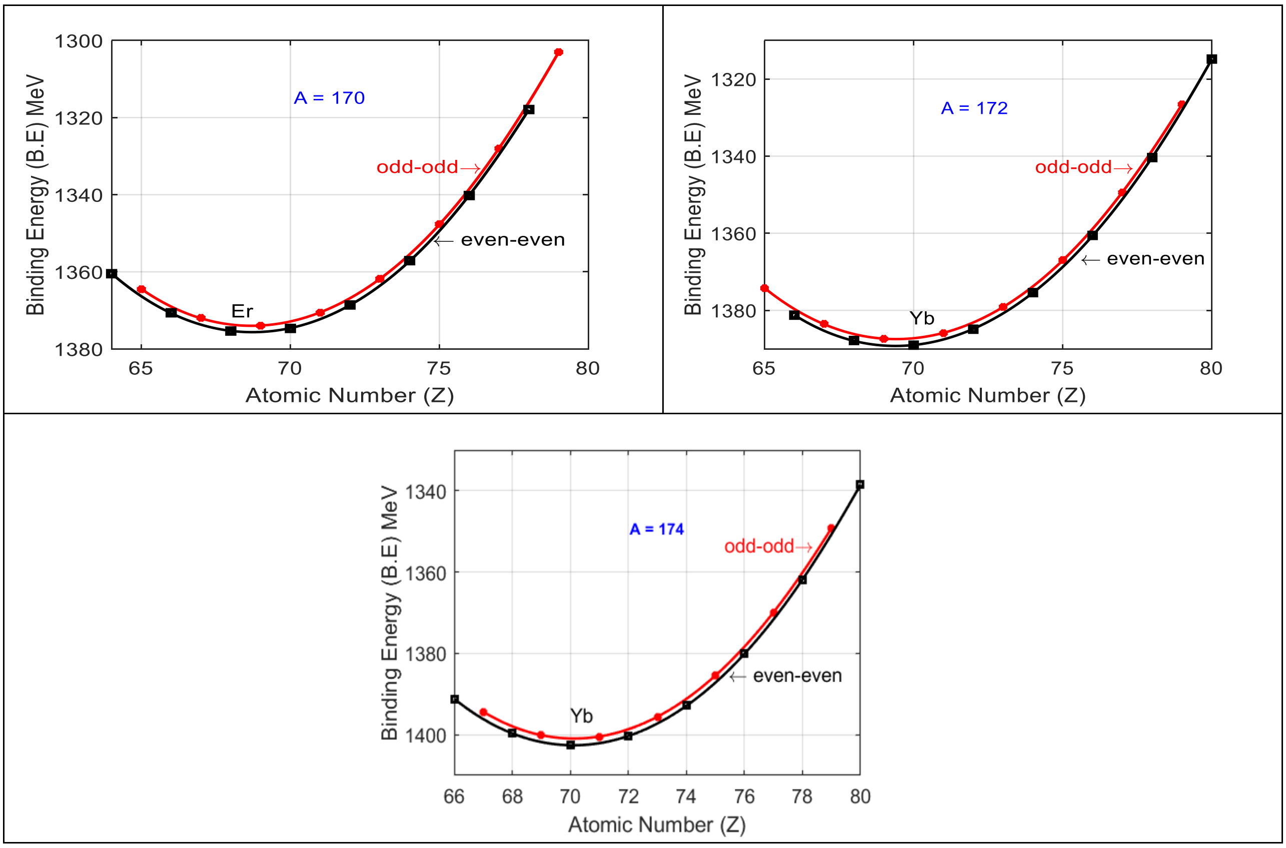


Figure 2. Mass parabolas for isobars with even mass number (A=165-175)

For several isobars, Figures (1&2) display the mass parabola that can be divided into two forms depending on the mass number value (A) odd or even. Figure (1) thus represents the mass parabola with mass number for various odd isobars (A=165,167,169,171,173 & 175). Figure (1) shows that the isobars with the odd value of mass number (A) have one mass parabola and in these isobars the pairing term equals zero, unrelated to the form of nucleus is even-odd or odd-even. There is also only one stable isobar, which has the maximum binding energy value (B.E.) at or near the bottom of the parabola.

Although figure (2) represents the mass parabola for isobars with an even mass number value (A), there are two mass parabolas for each mass number in this figure In the formula for binding energy, eq (1), because of the influence of the pairing term (positive for even nuclei and negative for odd nuclei), one of these mass parabolas for odd nuclei (black) and the other for even nuclei (red) which are binding energy formula eq.(1), the explanation for this is that the binding energy value for even-even nuclides is greater than the odd- odd nuclide binding energy value for the same mass number (isobar). The medium-mass nuclei possess more than stable paired isobar. We can also demonstrate from figures (1&2) that by increasing the atomic number to reach the most stable isobar, due to distance from the most stable isobar, the value of binding energy is increased and then decreased.

Calculation of the most Stable Isobars from the Isobars themselves' Atomic Number Values

The most stable isobar is also calculated by the atomic number (Z_A) estimate for most stable isobars from the equation (3). The results of (Z_A) for isobaric elements with mass numbers (A=165-175) are described in Table (1).

Table 1. Mass number (A), the most stable isobar ($\boldsymbol{Z_A}$) atomic number determined from equation (3) for nuclides with (A=165-175)

Mass number (A)	Atomic number for stable isobar (Z_A)
165	66.88809
166	67.24211
167	67.5957
168	67.94885
169	68.30157
170	68.65385
171	69.00571
172	69.35714
173	69.70814
174	70.05872
175	70.40888

Comparison between Two Methods of most Stable Isobar determined Mass Parabola and Atomic Number (Z_A)

For most stable isobars, the measured atomic number (ZA) values calculated from equation (3) for nuclides with mass number (A=165-175) are compared to their mass parabola values as shown in the table (2).

Table 2. A comparison between the mass parabolic method and the method of using the atomic number in the equation (3) in calculating the most stable isobars for nuclides with a mass number(A=165-175)

Mass number (A)	Nuclide –Atomic number for stable isobar from mass parabola	Atomic number for stable isobar (Z_A) equation (3)
165	Ho-67	66.88809
166	Er-68, Ho-67	67.24211
167	Er-68	67.5957
168	Er-68, Tm-69	67.94885
169	Er-68	68.30157
170	Er-68, Tm-69	68.65385
171	Tm-69	69.00571
172	Yb-70, Lu-71	69.35714
173	Yb-70	69.70814
174	Yb-70, Lu-71	70.05872
175	Lu-71	70.40888

Our comparison was made between stable nuclides calculated by two methods used in this analysis (the lowest point of the mass parabola for each isobar and those determined for the most stable isobars (Z_A) from the measurement of the atomic number) as shown in table (2) for the isobaric family (A = 165-175).

From this table, we can note that stable isobars are always the same nuclide in two methods for odd isobars, but in cases of even isobars having two stable isobars (only one of them are same stable isobars in comparison to the second method). Then the stable isobars are influenced by the binding energy value, as well as the ratio of the number of neutrons to the number of protons (N/P) and nucleon pairing.

Conclusions

The binding energy of the atomic nucleus depends primarily on the mass number, while the mass parabolas estimate the nuclear stability of the isobar. For nuclides with an odd mass number, there is just one parabola, whereas there are two parabolas for nuclides with an even mass number. The most stable isobars are found at the lower points of the parabola in both cases, so there is only one stable isobar for nuclides with an odd mass number, Whereas with nuclides with an even mass number, there is more than one stable isobar. In the state of contrast inter two techniques, stabilized isobars are permanently the same nuclide in two techniques for odd isobars, but in the state of even isobars with two stable isobars set from mass parabola (only one of them are selfsame stable isobars).

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