Investigation of One and Two Nucleon Separation Energies for Checking the Nuclear Stability in the region atomic number between 20 and 35

A Thesis submitted to post graduate program at the department of physics college of natural sciences, Jimma University, in partial fulfillment for the requirements of degree of masters of science in Physics

(Nuclear Physics)

By

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Declaration

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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Contents

List of Figures

List of Tables

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Abstract

Study and measuring nuclear binding energy are most active areas of nuclear structure physics. In this work, Bethe-Weisacker formula has been employed to study binding and nucleon separation energies of different isotopes and isotones for checking the nuclear stability in the region between atomic number 20 and 35. In data calculations, analytical and computational methods have been employed. The calculated binding energy by using Sci-lab computer soft-ware and graphs that were plotted by using xmgrace agree quite well with experimental data and were compared with values given in previous work for the purpose of validity. This work has determined, the relations between one nucleon and two nucleon separation energies with the nucleon number that were plotted Single and double nucleon separation energies in all possible manner and tried to discuss nuclear structure properties such magic nuclei, proton or neutron drip line, nuclear stability and so on. It is clear stated that even-Z and even-N nuclei, being most stable, are most abundant.The results show that stability of nuclei depends on the separation energy is high or not. Moreover, this work has incorporated to indicate many nuclides and transitions of a nuclei having high separation energy are highly stable and abundant.

Key words: Binding Energy, nucleon separation energy, Liquid Drop Model, Shell Model, magic number and nuclear stability.

1

Introduction

1.1 Back ground of study

Nuclear structural calculation far from the region of stability reveals new ideas which are not usually observed in the stability line. These studies provide information about the type of separation energy and the deformation exhibited by the nuclei. Ground state proton emission is an identification that the drip line has reached. To know about the two proton decay process, their separation energies need to be calculated. The special quality of proton rich nuclei is the di-proton emission. Due to pairing, a nucleus with an even number of protons is tightly bound than odd number of proton nucleus [1]. Hence the existence of two proton emission is sensitive to the two proton separation energies. More number of nuclei is found to undergo one proton emission either from the ground state or from an isomeric state or both. When the emitters are found to be deformed, it gives a check for the nuclear structure models at the drip line [2].

Systematic studies related to nucleon separation energies from the masses of nuclei provide evidence for shell closures. It is important to look for new shell closures or the disappearance of existing shell closures from the separation energy calculation. The origin of the unusual stability of nuclei with nucleon numbers 2, 8, 20, 28, 50, 82 and 126, commonly called to as magic numbers, is explained to be due to nuclear shell structure. At present there is a proliferation of new magic or rather quasi-magic numbers [3, 4]. 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 out of complex calculations. 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.

The shells for protons and for neutrons are independent of each other. Therefore, ”magic nuclei” exist in which one nucleon type proton or neutron is at a magic number, and ”doubly magic nuclei”, where both are. Due to some variations in orbital filling, the upper magic numbers are 126 and, speculatively, 184 for neutrons but only 114 for protons, playing a role in the search for the so-called island of stability. Some semi magic numbers have been found, notably $Z = 40$ giving nuclear shell filling for the various elements; 16 may also be a magic number [5].

The binding energy is usually plotted as binding energy per nucleon, B/A. The dependence of B/A on A (and Z) is captured by the semi-empirical mass formula. This formula is based on first principle considerations (a model for the nuclear force) and on experimental evidence to find the exact parameters defining it. In this model, the so-called liquid-drop model, all nucleons are uniformly distributed inside a nucleus and are bound together by the nuclear force while the Coulomb interaction causes repulsion among protons. Characteristics of the nuclear force (its short range) and of the Coulomb interaction explain part of the semi-empirical mass formula. However, other (smaller) corrections have been introduced to take into account variations in the binding energy that emerge because of its quantum-mechanical nature (and that give rise to the nuclear shell model).

Stability is all based on the nucleus tending towards the lowest energy state. Stable atoms have low energy states. Unstable atoms will try and become stable by getting to a lower energy state. They will typically do this by emitting some form of radioactivity and change in the process. The shell structure has been believed to be basically common not only among stable nuclei but also between stable and exotic (unstable) nuclei. The ionization energies vary with respect to the numbers of electrons of the atoms except at the shell edges, whereas the separation energies vary in a complicated way with the numbers of protons and neutrons. We have to understand the behavior of the dependence of the nuclear stability on separation energy for the third closed shell, those are atomic number 20-28 isotopes. By applying this knowledge we need a theory which gives the separation energies of nuclei as a function of the numbers of protons and neutrons for the higher mass region, whose sole behavior is not exactly known, because we must take into account the change of the nuclear structure when a nucleon is removed. This study will discuss such variation of separation energy relating with nucleon number of the isotopes and also investigate the relation with nuclear stability if one and two nucleon removed from the nucleus.

1.2 statement of the problem

Nucleon separation energy is the energy needed to remove nucleon (Proton, neutron) from a nucleus. For a given proton number, the neutron separation energy is larger for some nuclei than the other depending on whether the neutron numbers are odd or even [1]. Similarly for the proton separation energy with constant number of neutrons the energy needed to separate one proton or two protons is not the same; it rather depends on the number of neutrons in the nucleus [4].

Even-even nuclei occur most frequently than odd-odd nuclei in the table of stable nuclides available in nature. If stable nuclei were formed by a process in which increased binding energy produce increased abundance, we could deduce that those nuclei with higher value of binding energy are the most stable that is we can connect abundance with stability. This may has some connection with systematic of separation energies of the nucleon [6]. In this thesis therefore we can justify stability of a nucleus as evidenced by nucleon separation energies for a range of isotopes with proton number between 20 and 35.

The research leading questions that were answered are:

1. What relations are there between single nucleon and two nucleon separation energies and the nucleon number?

2. What are the factors that affect nucleon separation energy of nuclei for a given

proton/neutron number?

3. What conclusion can be drawn to predict nuclear stability from nuclear separation energies?

1.3 Objectives of the study

1.3.1 General Objective

The main objective of this study is to calculate one nucleon and two nucleon separation energies and investigate the relation between the separation energies and the nuclear stability of medium mass (i.e $20 \leq Z \leq 35$).

1.3.2 specific objectives

The specific objectives of this study are :

1. To explain the relations between one nucleon and two nucleon separation energies with the nucleon number.

2. Discuss the factors that affect nucleon separation energy of nuclei for a given nucleon number.

3. To clarify the relation of nucleon separation energies and stability.

1.4 Significance of the Study

Obtaining theoretical conclusion on the application of nucleon separation energies to check for the nucleon closed shells and nuclear stability for the given isotopes which lies below the second nucleon closed shell is the main relevance of this research. In addition it can be used as a reference to use in similar researches.

1.5 Limitation of the Study

The research study was not free from limitation. Lack of advanced laboratory made to limit the study only theoretical consideration. similarly Due to time constraint the study were limited to calculation of nucleon separation energies for the isotopes whose structure lies in the second closed shell region, other shell closures were not be checked. The other limitations that might bring some impact on the result of the study are lack of recurrence material and finance and also lack of sufficiently fast internet connection in the local area where the research thesis was developed.

2

Review of Literature

2.1 Models of Nuclear Structure

A goal of nuclear physics is to account for the properties of nuclei in terms of mathematical models of their structure and internal motion. Two important nuclear models are the Liquid Drop Model and the Shell Model (developed by Maria Goeppert-Mayer and Hans Jensen) [5], which emphasizes the orbits of individual nucleons in the nucleus[3]. The Liquid Drop Model treats the nucleus as a liquid. Nuclear properties, such as the binding energy, are described in different parameters that are usually associated with a liquid. This model has been successful in describing how a nucleus can deform and undergo fission.

The Nuclear Shell Model is similar to the atomic model where electrons arrange themselves into shells around the nucleus. The least tightly-bound electrons (in the incomplete shells) are known as valence electrons because they can participate in exchange or rearrangement, that is, chemical reactions [3]. The shell structure is due to the quantum nature of electrons and the fact that nucleons are fermionsparticles of half-integer spin. Consequently the fermions in a bound system will gradually fill up the available states: the lowest one first, then the next higher unoccupied state, and so on up to the valence shell [4].

2.2 Liquid drop model

One of the first nuclear models, proposed in 1935 by Bohr, is based on the short range of nuclear forces, together with the additivity of volumes and of binding energies. It is called the liquid-drop model. Nucleons interact strongly with their nearest neighbors, just as molecules do in a drop of water. Therefore, one can attempt to describe their classical properties by the corresponding quantities, i.e. the radius, the density, the surface tension and the volume energy.

An excellent parameterization of the binding energies of nuclei in their ground state was proposed by Bethe and Weizsacker [7]. This formula relies on the liquid-drop analogy but also incorporates different quantum ingredients. One is an asymmetry energy which tends to favor equal numbers of protons and neutrons. The other is a pairing energy which favors configurations where two identical fermions or nucleon are paired.

- The nucleons in a nucleus behave like molecules in the liquid drop.
- The emission of nuclear radiations (n, p, d and so on) from nucleus is analogous to the emission of the molecules from the liquid drop during evaporation.
- The constant B.E. per nucleon is analogous to the constant latent heat of vaporisation of the liquid.

The average behaviour of the nuclear binding energy can be understood with the model of a charged liquid drop. In this model, the aggregate of nucleons has the same properties of a liquid drop, such as surface tension, cohesion, and deformation. There is a dominant attractive binding energy term proportional to the number of nucleons A. From this must be subtracted a surface-energy term proportional to surface area and a coulombic repulsion energy proportional to the square of the number of protons and inversely proportional to the nuclear radius. Furthermore, there is a symmetry-energy term of quantum-mechanical origin favouring equal numbers of protons and neutrons. Finally, there is a pairing term that gives slight extra binding to nuclei with even numbers of neutrons or protons.

2.3 Nuclear Shell model

Atomic theory based on the shell model has provided remarkable classification of the complicated details of atomic structure. Nuclear physicists therefore attempted to use a similar theory to attack the problems of nuclear structure in the hope of similar success in classifying the properties of nuclei. In the atomic shell model we fill the shells with electrons in order of increasing energy consistent with the requirement of the Pauli principle. when we do so, we obtain an inert core of filled shells and some number of valance electrons; the model then assumes that atomic properties are determined primarily by the valance electrons. in particular we see regular and smooth variations of atomic properties within a sub-shell, but rather sudden and dramatic changes in the properties when we fill one sub-shell and enter the next[8].

Nuclei near major shell closures may be described microscopically by the shell model. The properties of these nuclei have been predicted in good agreement with experiment considering an extreme single-particle shell model. According to this model, the properties of the nucleus are dictated by the behavior of a single unpaired nucleon.

These models are necessary for the extrapolation of single-particle properties of nuclei far from stability[5]. Doubly-magic nuclei those that have a magic number for both protons and neutrons are crucial for the understanding of nuclear structure. The closed-shell property of the doubly-magic nuclei provides a good zeroth-order wave function which can be systematically improved upon by using perturbation theory. Starting with a zero-particle zero-hole (0p-0h) closed shell, the structure of the closed shells themselves can be systematically improved by the mixing of 2p-2h and higher excitation.

- The binding energies of magic-number nuclei is much larger than in the neighboring nuclei. Thus larger energy is required to separate a single nucleon from magic nuclei.
- The number of stable nuclei with magic values of proton number, Z or neutron number, N is much larger than the corresponding number in neighboring nuclei.
- Naturally occurring isotopes with magic Z or N have greater relative abundances.
- The first excited states in nuclei with magic numbers of neutrons or protons lie at higher energies than the same states in neighboring nuclei.

There is thus a correction term in the Semi-emprical mass formula which tries to take into account the symmetry in protons and neutrons. Symmetry and pairing term correction can only be explained by a more complex model of the nucleus, the shell model, together with the quantum-mechanical exclusion principle.

2.4 Estimating Binding energy using Bete-Von Weisacker formula

2.4.1 Binding energy of the nuclei

The mass of an atomic nucleus is less than the sum of the individual masses of the free constituent protons and neutrons, according to Einstein's equation $E = mc^2$ [9]. This 'missing mass' is known as the mass defect Δm, and represents the energy that was released when the nucleus was formed.The binding energy is equal to the amount of energy released in forming the nucleus, and is therefore given by

$$B.E = \Delta mc^2 \tag{2.1}$$

Binding energies are crucial to understand why a nucleus exists, and they can be used to explain why only specific combinations of protons and neutrons are found in nature or in experimental nuclear physics facilities.
The mass of a stable nucleus in its ground state is always less than the masses of the protons and neutrons composing the nucleus. We write the energy of the nucleus in the ground state [10, 11]:

$$E(A, Z) = M(A, Z) - ZMp - (A - Z)Mnc^2 \tag{2.2}$$

where E(A,Z) is the mass of the nucleus and Mp and Mn are the mass of the proton and neutron respectively. The quantity $E(A, Z)$ taken with the opposite sign is called the binding energy. Clearly, the binding energy is the work that must be expended to break up the nucleus into its constituent particles.
The binding energy of an isotope of element Z with N neutrons is defined by the difference:

$$B.E = [Nm_n + Zm_p - M(N, Z)]c^2 \tag{2.3}$$

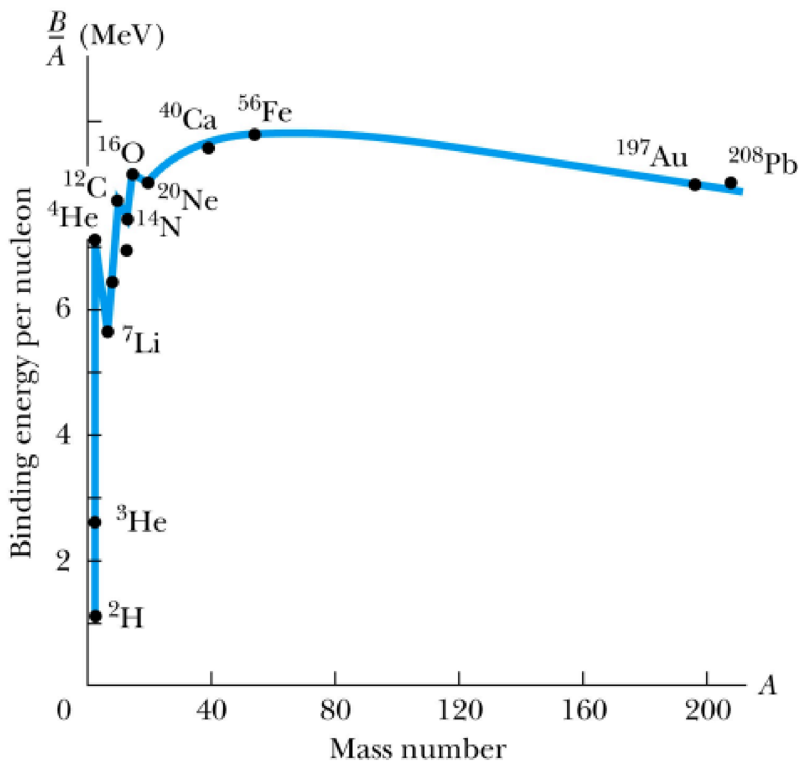

Figure 2.1: Average binding energy per nucleon (MeV) versus mass number, A

where $m_n c^2$ = 939.565 MeV and $m_p c^2$ = 938.272 MeV represent the rest mass energies of the neutron and the proton, and M(N,Z) is the rest mass of the nucleus itself. The binding energy per nucleon is characteristic of the stability of the nucleus. Figure 2.1 shows the dependence of the mean binding energy per nucleon on the mass number, A for different nuclei. The binding energy per nucleon first increases rapidly with increasing A, attaining a value of 8 MeV by A = 16, then increases very slowly to a value of 8.8 MeV at A 60, and then decreases very slowly, taking the value 7.4 MeV for the heaviest nuclei [8].

The most characteristic feature of this dependence is the fact that the mean binding energy per nucleon is approximately constant (8 MeV) over almost the whole range of variation of A, with the exception of the region of very light nuclei. Consequently, the total nuclear binding energy, like the nuclear volume, is proportional to the number of nucleons in the nucleus. Small deviations from this proportionality are connected with surface effects, the Coulomb repulsion between the protons, the difference between the numbers of protons and neutrons, and the effect of the parity of the numbers of protons and neutrons. The fact that the mean binding energy per nucleon, like the volume per nucleon, is independent of the number of nucleons in the nucleus can be explained by assuming that the nuclear forces between the nucleons possess the property of saturation, that is, each nucleon in the nucleus can interact only with a small number of nearest nucleons. As binding energy per nucleon increases the nuclear stability of light nuclei highly increase.

The saturation of the nuclear forces points to an analogy between the properties of the nuclear substance and those of an ordinary liquid. On the basis of this analogy, a liquid-drop model of the nucleus is introduced, according to which the nucleus can be regarded as a drop of nuclear liquid. The liquid-drop model of the nucleus makes it possible to explain the dependence of the nuclear binding energy on the mass number A and the charge Z of the nucleus.

2.4.2 Weisacker formula for Binding Energy

The analogy between nucleus and liquid drop has been used to set up a Weisacker (semi-empirical) formula for mass (or binding energy) of a nucleus in its ground state [10]. The formula has been obtained by considering different factors of the nucleus binding. The binding energy B of a nucleus is given by the sum of five terms as

$$B = B_1 + B_2 + B_3 + B_4 + B_5 \tag{2.4}$$

Which are explained as under different terms:

Volume Energy Term (B_1): The binding energy is a measure of the interaction among nucleons. Since nucleons are closely packed in the nucleus and the nuclear force has a very short range, each nucleon ends up interacting only with a few neighbors. This means that independently of the total number of nucleons, each one of them contribute in the same way. This is same as the binding energy of the drop B. So

$$B = LMnN \tag{2.5}$$

where N is the number of molecules in the drop. Equation (2.5) can also be written as

$$\frac{B}{N} = LMn = constant \tag{2.6}$$

This means that B/N is independent of the number of molecules present in the liquid drop. As we know that in the liquid drop, a molecule interacts only with its nearest

neighbours and number of neighbors is independent of the size of the drop. The neutrons and protons are held together in nuclei by short range attractive forces.
Since the volume of the nucleus is proportional to A, hence this term is regarded as a volume binding energy and in analogy above equation is given by:

$$B_1 = a_v A \tag{2.7}$$

where a_v is a proportionality constant and subscript v is for volume.

The surface term(B_2): is a correction to the volume term to take into account that the nucleons at the surface of the nucleus do not have the same level of interactions as nucleons in the interior of the nucleus. In the above volume term discussion, we have assumed that all the molecules are surrounded by its neighbors, while in actual practice the molecules at the surface do not have any neighbors on all the sides. So these molecules are not as tightly bound as the molecules in the interior. Extending this argument to the nuclear case, some nucleons are nearer to the surface, and so they interact with fewer nucleons [10].
Thus, the binding energy is reduced by an amount proportional to the surface area of the nucleus of radius r as the nucleons on the surface are less tightly bound than those in the interior. This term is proportional to the surface area of the nucleus of radius $R = r_0 A^{\frac{1}{3}}$. Therefore,

$$B_2 \propto -4\pi r^2 \tag{2.8}$$

$$B_2 \propto -4\pi r_0^2 A^{\frac{2}{3}} \tag{2.9}$$

Which is usually expressed as:

$$B_2 = -a_s A^{\frac{2}{3}} \tag{2.10}$$

Where negative sign is for decrease in energy and a_s is constant.

Coulomb Energy Term (B_3): The Coulomb term represents the energy incorporated in the nucleus as a result of the positive charge present in the nucleus. The only long-range force in the nucleus is the Coulomb repulsion between protons [10]. The total work done in assembling a nucleus consisting of Z protons is given by:

$$W = \frac{\frac{3}{5} Z^2 e^2}{4\pi\epsilon_0 r} \tag{2.11}$$

Where r is the radius of the nucleus. For a single-proton nucleus

$$w = \frac{\frac{3}{5} e^2}{4\pi\epsilon_0 r} \tag{2.12}$$

For a nucleus having Z protons

$$w^{'} = \frac{\frac{3}{5} Z e^2}{4\pi\epsilon_0 r} \tag{2.13}$$

For a single-proton nucleus no work is done against Coulomb repulsion in assembling the nucleus. Thus, the true Coulomb energy term for a nucleus containing Z protons is the difference between eq. (2.24) and (2.26).

$$B_3 = -[\frac{\frac{3}{5} Z^2 e^2}{4\pi\epsilon_0 r} - \frac{Z \frac{3}{5} e^2}{4\pi\epsilon_0 r}] \tag{2.14}$$

That is

$$B_3 = -\frac{3}{5} \frac{Z(Z-1)e^2}{4\pi\epsilon_0 r} \tag{2.15}$$

The negative sign indicates the repulsive term. As $R = r_0 A^{\frac{1}{3}}$, then

$$B_3 = -a_c \frac{Z(Z-1)}{A^{\frac{1}{3}}} \tag{2.16}$$

where a_c is constant.

Asymmetry Energy Term (B_4): The asymmetry term reflects the stability of nuclei with the proton and neutron numbers being approximately equal. This is a term, which depends on the neutron excess (N-Z) in the nucleus and it decreases with the increasing nuclear binding energy. For very few nuclei of low Z, N-Z = 0 and are more stable compared to their neighbors, i.e. their binding energies are maximum. The reduction in binding energy for higher A nuclei is directly proportional to $(N-Z)^2$ or square of excess of neutrons and is inversely proportional to mass number. So, we can write

$$B_4 \propto \frac{(N-Z)^2}{A} \tag{2.17}$$

Table 2.1: Four group of stable nuclei

Z	N	Number of stable nuclide
Even	even	165
Even	odd	55
Odd	even	50
Odd	odd	5

$$B_4 = -a_a \frac{(A-2Z)^2}{A} \tag{2.18}$$

As A = N + Z and a_a is constant.

Pairing Energy Term (B_5): So far we have all the terms in the binding energy have smooth variation with respect to N or Z or A. This fact did not appear in the liquid drop model, which does not consider intrinsic spin of the nucleons and the shell effects. It is interesting to classify all the stable nuclei into four groups, first having even-even , even-odd N, odd-even and odd Z-N.

From Table 2.1, it is clear that even-Z and even-N nuclei, being most stable, are most abundant. Accordingly, odd-Z and odd-N nuclei are least abundant and hence least stable. The remaining nuclei have intermediate stability. Therefore, the binding energy also depends upon whether the number of protons and neutrons are odd or even. This pairing effect was incorporated by putting:

$$B_5 = a_p A^{-\frac{1}{2}} \tag{2.19}$$

Substituting the values of B_1, B_2, B_3, B_4 and B_5 from above term Equations, then the Weisacker formula for Binding Energy is:

$$B = a_v A - a_s A^{\frac{2}{3}} - a_c \frac{Z(Z-1)}{A^{\frac{1}{3}}} - a_a \frac{(A-2Z)^2}{A} + a_p A^{-\frac{1}{2}} \tag{2.20}$$

The various constants found are:

a_s=16.8MeV

a_c=0.7MeV

a_a=23.0MeV

a_p=34MeV, 0MeV, -34MeV for even-even, even-odd and odd-odd nuclei respectively.

2.5 Nuclear stability

For stable nuclides having atomic number $Z < 20$, N=Z, for $Z > 20$ the number of neutrons has to be greater than Z for stability of the nucleus. This is because for stable nuclei having large values of Z. The Coulomb force of repulsion between the protons becomes very large. In order to compensate the large repulsion force there has to be greater number of neutron [11]. Nature seeks the lowest energy state. In the lowest energy state, things are most stable...less likely to change. One way to view this is that energy makes things happen. If an atom is at its lowest energy state, it has no energy to spare to make a change occur. The following information that talks about stability is all based on the nucleus tending towards the lowest energy state. Stable atoms have low energy states. Unstable atoms will try and become stable by getting to a lower energy state. They will typically do this by emitting some form of radioactivity and change in the process.

Heisenberg and Majorana proposed in 1933 a theory of nuclear forces based on the proton neutrons constitution of the nucleus and a suitable combination of the liquid drop and shell models, which was able to explain several of the experimentally observed facts concerning the stability of nuclei satisfactorily though not completely. Majorana also explain the electrostatic repulsive forces between the protons in the nucleus.

However, because of the saturation character of the intra-nuclear forces, the Coulomb repulsion between the protons becomes important for heavy nuclei. The Coulomb forces show no saturation. Hence the total energy of the Coulomb interaction need not be proportional to the mass number A. The binding energy per nucleon will therefore decrease, on account of the electrostatic force; with increasing mass number as is actually the case with heavier nuclei, this work in the opposite direction from the surface tension effect.

It is fount that nuclear forces holding the nucleons together inside the nucleus, which are short range, basically very strong about 10^{38} times as strong gravitational forces, charge independent (i.e, n-p= n-n =P-P), charge symmetric, spin dependent and non-central forces. These forces of attraction are much larger than the electrostatic force of repulsion between the protons, thus giving stability to the nucleus.

2.6 Nucleon separation Energy

Separation energy is the energy needed to remove one nucleon (or other specified particle or particles) from an atomic nucleus. The separation energy is different for each nuclide and particle to be removed. Values are stated as "neutron separation energy", "two-neutron separation energy", "proton separation energy", "deuteron separation energy", "alpha separation energy", and so on [12]. Difference of binding energy of two neighboring isotopes yield the separation energy of one neutron. The smallest energy required to remove a nucleon from the nucleus is the separation energy (S). For medium heavy nuclei the separation energy for a neutrons n is approximately equal to the separation energy for a proton S_p, but for lighter nuclei both S_n and S_p show considerable fluctuations.

By contrast, nuclear binding energy is the energy needed to completely disassemble a nucleus, or the energy released when a nucleus is assembled from nucleons. It is the sum of multiple separation energies, which should add to the same total regardless of the order of assembly or disassembly.

Nucleon separation energy plays an important role in predicting new shell closures in the proton and neutron drip line nuclei. The one and two nucleon separation energies are fundamental properties of the atomic nucleus. The systematic study of proton and neutron separation energies is essential to investigate nuclear structure toward drip lines [12, 13]. In literature it is understood that the energy spend in removing two fermions from a system of identical fermions shows system stability. If the pairing dominates in fermion-fermion interaction, then energy required to separate two fermions for even number of particles will be much higher than odd number. These characteristics can be observed from the study of two neutron separation energy S_{2n}. It is known

that in neutron-rich nuclei, odd magic numbers disappear and new ones appear.
The drip line is reached when the separation energy reaches zero; hence, for example one can talk about the one-neutron drip line when S_n = 0 and the two-neutron drip line when S_{2n} = 0. Very weakly bound, or unbound, nuclei that lie in the immediate vicinity of drip lines are referred to as threshold systems.
One neutrons separation energy is the required energy to remove One neutrons from a nucleus with Z protons and N neutrons.
The proton- and the neutron separation energy of a nuclide with numbers N and Z are given by:

$$S_p(N,Z) = B(N,Z) - B(N,Z-1) \tag{2.21}$$

$$S_n(N,Z) = B(N,Z) - B(N-1,Z) \tag{2.22}$$

The $B(N,Z)$ is the binding energy of the nuclide related to its mass $M(N,Z)$:

$$M(N,Z) = ZM_H + Nm_n - B(N,Z) \tag{2.23}$$

WhereM_H and m_n are masses of the hydrogen atom and the neutron, respectively. When we move along the line of isotopes with the given atomic number Z, starting from stability towards nucleon-deficient nuclides, the proton/neutron separation energy S_p decreases and at certain location it becomes negative. The proton drip-line is defined as the border between the last proton-bound isotope and the first one with the negative value of the S_p.
The drip lines as defined above are very useful in identifying and discussing limits of stability, but to some extend they are arbitrary and they do not provide the unambiguous demarcation of nuclear stability. This can be seen by inspecting the two-nucleon separation energies [14]:

$$S_{2P}(N,Z) = B(N,Z) - B(N,Z-2) \tag{2.24}$$

$$S_{2n}(N,Z) = B(N,Z) - B(N-2,Z) \tag{2.25}$$

The particle stability of a nuclide is determined by its separation energy, i.e., the energy required to remove from it a single nucleon or a pair of like nucleons. If the separation energy is positive, the nucleus is bound to nucleon decay; if the separation energy is negative, the nucleus is particle-unstable.

3

Materials and Method

3.1 Materials

The following list of materials and Soft-wares were used during the work: Computer, printer, Sci-lab computer soft ware, Published Articles and Journals and Books, Flush disc and Stationary materials.

3.2 Method

3.2.1 Analytic Method

The resulting output of level the separation energies were plotted as a function of neutron number and proton number to see the pattern and some conclusion were drawn to predict the nuclear stability from the data (that displayed in table).

3.2.2 computational method

Using liquid drop model the weiszacker formula derived equations a Sci-Lab software were used to calculate Binding energy and then one nucleon and two nucleons separation energies. Using the calculated data, the nucleon separation energies for those isotopes and isotones (stable and unstable) [15,16] which lies under the second closed shell in their structure were calculated and the result were listed in a table and saved in a computer.

4

Results and Discusion

4.1 Results and Discussion

Under this section the one and two Nucleon separation energies for checking the Nuclear stability in the region between atomic number 20 and 35 were discussed. Firstly binding energy(BE) were calculated by using Bethe-Weisacker mass formula (equation 2.20). After these calculation of Binding energy were finished, we were able to use these binding energies to calculate different single and double nucleon separation energy values for single proton(S_p), single neutron(S_n), two protons(S_{2p}), and two neutrons(S_{2n}) by using equation 2.21, 2.22, 2.24, and 2.25 respectively, for different isotones and isotopes of atomic number between 20 and 35 (i.e Ca, Sc, Ti, V, Cr, Mn, Ir, Co, Ni, Cu, Zn, Ga, Ge, As, Se, and Br). The separation energies calculated for different proton numbers, Z for fixed values of neutron number, N and different neutron numbers for various fixed Z values. All data of Binding energy and separation energy calculated were presented in table 4.1.

4.2 Single Nucleon Separation Energy in the region $20 \leq Z \leq 35$

Under this section Single proton and Single neutron separation as a function of nucleons were discussed depends on the data from the calculation of Single nucleon separation energies in the region of $20 \leq Z \leq 35$ which were displayed in the table 5.1.

4.2.1 Single proton Separation Energy for fixed proton number

As we can see in Figure 4.1, Single proton separation energy increases as the neutron number of the given isotope increase. We can understand here that, additional neutrons requires to assure nuclear stability this is because of the asymmetry term effect. For instance Scandium isotopes black colored (Z=21) curve, the single proton separation energy of ^{40}Sc (S_p = 0.4 MeV) is about 1/50th of ^{61}Sc (S_p = 21.72 MeV), in Titanium isotopes red colored (Z=22) curve, ^{39}Ti have (S_p = 1.04 MeV) but ^{62}Ti have (S_p = 23.21 MeV), which is much much greater than separation energy of ^{39}Ti. And also ^{96}Br have a 14.68 MeV single proton separation energy which is 60 times greater than single proton separation energy of ^{69}Br is (S_p = 0.24 MeV). And this increasing pattern in the given Figure 4.1 is true for all isotopes of the nuclei in the region of atomic number between 20 and 35.

When we move along the line of isotopes with the given atomic number Z, starting from stability towards neutron-deficient nuclides, the proton separation energy S_p decreases and at certain location it becomes negative. This point is proton drip-line that is the border between the last proton-bound isotope and the first one with the negative value of the S_p. In this region there are isotopes having negative separation energy. These negative separation energy indicates that nucleon will not bind to the rest of the nucleus. Such a configuration is also called particle unstable, because the nucleus will decay by proton emission. Therefore the location of the drip line is determined by the separation energy crossing zero. These isotopes are unstable (that is, radioactive) nuclei. Thus, the one proton drip line is reached when Sp $\leq$ 0, which means the proton-drip line lies close to the valley of stability. (For instance as shown in Figure 4.1 the ^{38}Sc, ^{45}Mn, ^{46}Mn, ^{48}Co, ^{49}Co, ^{49}Ni, ^{50}Ni, and soon have negative value of one proton separation energy).

The isotopes of the atomic number between 20 and 35, single proton separation energy increases as a function of neutron number increase, especially in different isotopes at N= 20, 28, and 50 it suddenly increases as it approaches the magic nuclei. The sharp discontinuities in separation energies correspond to filling of shells in the single proton separation energies of sequences of isotopes. Which means hardly affects the values of S_p when N = 20, 28, 50. This is a consequence of Neutron numbers being a magic

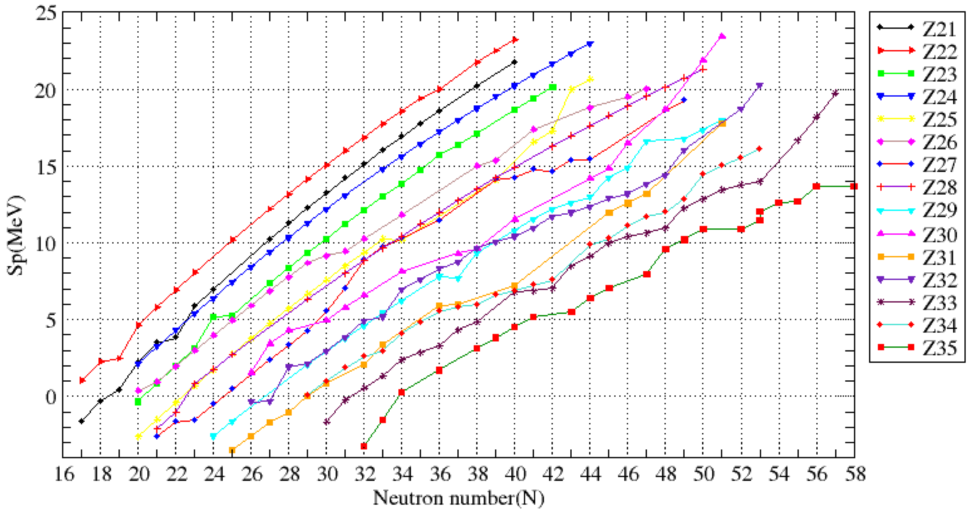

Figure 4.1: Single proton separation energy as a function of N for different Z values.

number.

4.2.2 Single Neutron Separation Energy for fixed proton number

Under this section the discussion is based on Figure 4.2 and 4.3, One Neutron Separation Energy as a function of neutron for constant proton number we can see that separation energy is noticeably higher if the number of neutrons is even. If a neutron is removed from a nucleus with an even number of neutrons, a pair must be broken up that requires additional energy. A single neutron separation energy not follow the same pattern with single proton separation energy discussed above, rather it fluctuate depending on the evenness and oddness of the nucleon numbers of the nuclei as described pairing term in weisacker formula. Nuclear pairing generally tends to stabilize even-even species than their odd-odd neighbors. Because of this in the Figure 4.2 the maximum (up) peaks have even-even nuclei while minimum (down) peaks have odd neutron number. Similarly Figure 4.3 the up peaks have even neutron while down peaks have odd neutron number. Due to this stabilization, the one-nucleon drip lines are reached earlier in the nuclear landscape than the two-nucleon drip lines.

This shows that in most cases the nuclei of even nucleon number is more stable than that of odd nucleon number. And also, the single neutron separation is higher to transit from doubly magic nuclei (both proton and neutron number magic) than atomic number magic nuclei. For instance, the single neutron separation energy needed to separate a neutron from ^{36}Ca to transit to ^{35}Ca is more than approximately by 5 MeV of separation energy needed to separate a neutron from ^{37}Ca to transit to ^{36}Ca. Like that of single proton separation energy, in case of single neutron separation energy there are negative separation energies. These negative energies occur when a neutron separated from nuclei of odd nucleon number. In this case isotopes which have a constant number of protons but a varying number of neutrons were considered. For the neutron-rich isotopes of each element, the limit at which any additional neutron will not be bound is called the neutron drip line.

The one-neutron separation energy becomes negative as the neutron drip line is crossed. This means that a nucleus beyond the neutron drip line gains a more stable configuration by emitting one neutron directly. The location of the neutron drip line coincides with the limit of existence of the nucleus, meaning that nuclei beyond the neutron drip line will decay.

Also As shown in Figure 4.2 the neutron separation curve become high at magic number 28 at some extents of points. It shows that separation energies disclose rich nuclear structure information. They indicate very clearly the major shell closures at double magic number (N=28 and Z=28) reflected by discontinuities of one-neutron separation energy as a function of N that is ^{56}Ni in Figure 4.2 yellow colored curve. And also ^{42}Ti and ^{50}Ti have high one-neutron separation energy because of its N=20 and 28 magic numbers respectively. Nuclear pairing generally tends to stabilize even-even species with respect to their odd-mass or odd-odd neighbors. Because of this in the Figure 4.2 and 4.3 the maximum (up) peaks have even neutron while minimum (down) peaks have odd neutron number number.

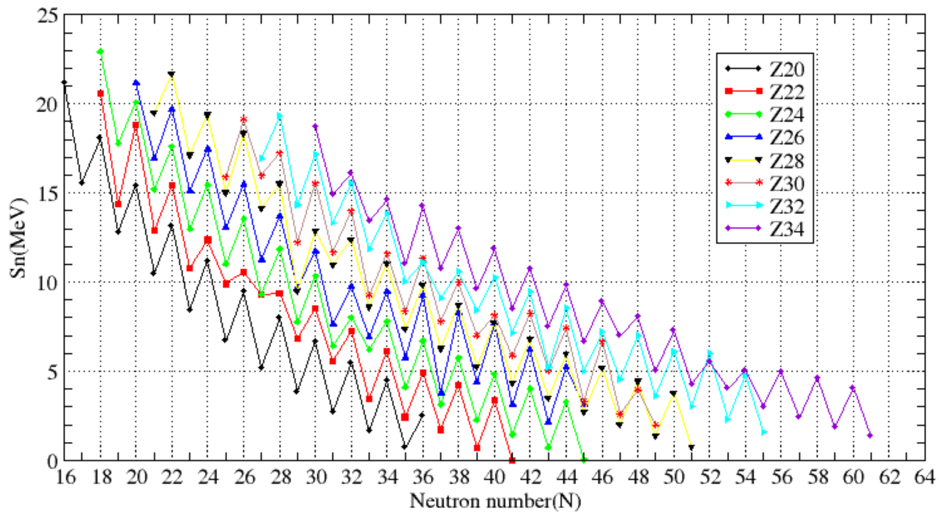

Figure 4.2: Single neutron separation energy as a function of N for different even-Z values.

4.2.3 Single Neutron Separation Energy for fixed Neutron number

As shown in Figure 4.4, single neutron separation energies for isotones corresponding to N = 18 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, and 32 were plotted. One-Neutron separation energies isotonic transition (For instance ^{38}Ca to ^{37}Ca, ^{39}Sc to ^{38}Sc, ^{40}Ti to ^{39}Ti, and ^{42}Cr to ^{41}Cr, have a value of 18.06 MeV, 19.35 MeV, 20.56 MeV, and 22.92 MeV respectively) for N=18 black colored curve and other isotones were calculated as a proton numbers varies. As we can see here one neutron separation energy is increases as proton number increase because of the asymmetry energy term effect since its effect is smaller for larger A.

In this section we can found that magic numbers appear and some others disappear in moving from stable to exotic (unstable) due to its neutron-neutron interaction. As shown in Figure 4.4 the one neutron separation become continuously steep up at some extents of points, but it was discontinuity at middle point as the proton number increase,that is when we compare N=20 green colored curves have high separation energy

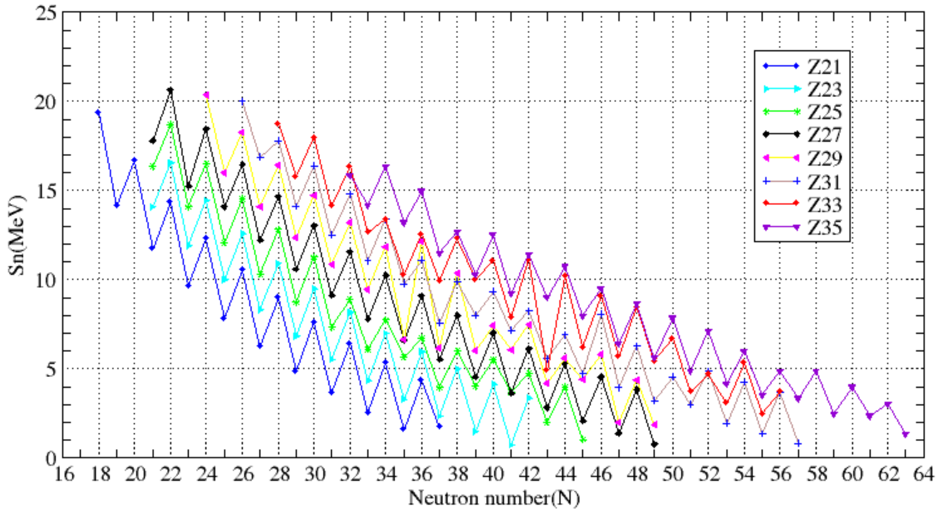

Figure 4.3: Single neutron separation energy as a function of N for different odd-Z values.

than N=19 red colored curves which indicate very clearly that the magic shell closures at magic number of neutron. The study of Figure 4.4 gives the information that the values of neutron separation energy of the nearest nuclei of magic nuclei are less than that of the magic nuclei.

4.2.4 Single proton Separation Energy for fixed Neutron number

Figure 4.5 were plotted for Single proton separation as a function proton number for fixed neutron number. When we move along the line of isotones, starting from stability towards neutron-deficient nuclides, the proton separation energy S_p decreases and at certain location it becomes negative. For example in Figure 4.5 black colored (N=20)the isotonic transition (i.e ^{41}Sc to ^{40}Ca, ^{42}Ti to ^{41}Sc, ^{43}V to ^{42}Ti, ^{44}Cr to ^{43}V, ^{45}Mn to ^{44}Cr, ^{46}Fe to ^{45}Mn, and ^{47}Co to ^{46}Fe) have one proton separation energy 2.23 MeV, 4.63 MeV, -0.33 MeV, 2.13 MeV, -2.61 MeV, 0.39 MeV, and -1.16 MeV respectively. When we increase protons, asymmetry and Coulomb term reduces the binding energy. Therefore steeper

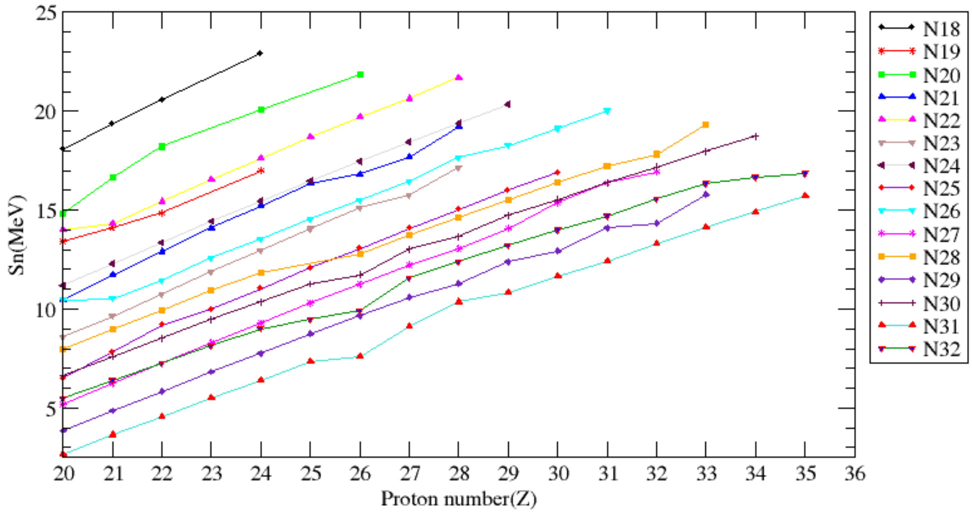

Figure 4.4: Single neutron separation energy as a function of Z for different N values.

drop of proton separation energy is observed and the drip line is reached much sooner. Increasing of protons makes decrease Binding energy as well as separation energy . This is because of Coulomb repulsion which makes a nucleus containing many protons less favorable for stability.

In addition, according to the pairing term in the Weisacker formula, as the above example indicates, an even number of particles is more stable than odd number. The single neutron separation energy needed to separate one neutron from even nuclei to odd nuclei is greater than neutron separation needed to separate single neutron from odd to even nuclei as shown in Figure 4.5. Because of this the maxima (up) peaks have even proton while minima (down) peaks have odd proton number. The tendency to form proton pairs and neutron pairs is a consequence which arises from this energy term. And also binding energy is high if we have an even-even nucleus, where all the neutrons and all the protons are paired.

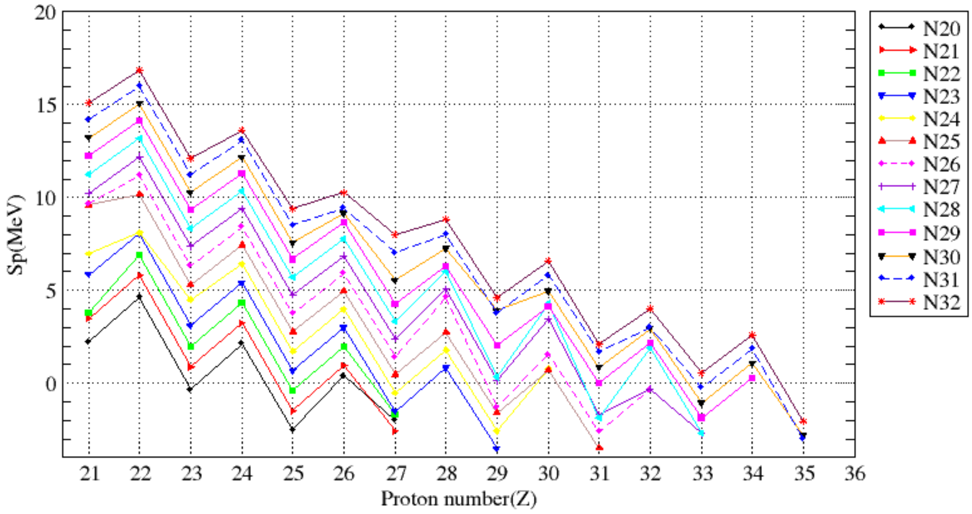

Figure 4.5: Single proton separation energy as a function of Z for different N values.

4.3 Two Nucleon Separation Energy in the region $20 \leq Z \leq 35$

Under this section the discussion for the separation energies of two proton and two neutron have been given depends on the data from the calculation of two nucleon separation energies in the region of $20 \leq Z \leq 35$ which displayed in the table 5.1 and 5.2.

4.3.1 Two Protons Separation Energy for fixed neutron number

In this work two-protons separation energy as a function of proton number for fixed neutron number (Neutron number =20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, and 32) were calculated. As shown in the Figure 4.6 two proton separation energy decreases as a function of proton number for fixed neutron. Due to increasing of proton number the mass number, A will be large. Because the increasing of the difference between the number of proton and number of neutron the effect of asymmetry energy term become high. Then the two proton separation energy will be decreased.

Similarly the stability of the nuclei will be reduced due to high coulomb's repulsion force in case of adding protons for fixed neutron number. Therefore steeper drop of two-proton separation energy is observed and the drip line is reached much sooner. As shown on the Figure 4.6, for the neutron-rich isotopes of each element, the limit at which any additional neutron will not be bound is called the neutron drip line. The two-proton separation energy becomes negative as the neutron drip line is crossed. The location of the neutron drip line coincides with the limit of existence of the nucleus, meaning that nuclei beyond the neutron drip line decay. We can see here that the energy needed to separate two- protons from a given isotone is negative such as (^{46}Fe to ^{44}Cr, ^{47}Co to ^{45}Mn, ^{48}Co to ^{46}Mn, ^{48}Ni to ^{46}Fe, ^{49}Ni to ^{47}Fe, ^{52}Cu to ^{50}Co, ^{53}Cu to ^{51}Co, ^{53}Zn to ^{51}Ni, and soon) are negative. Hence, they are not bounded.

And also, as shown in Figure 4.6, when we go from right to left, as proton number decreased, the increment of two-proton separation energy is large amount of factor as isotopes approaches magic nuclei and again it return to the slightly increasing as it goes before. For example the green colored (N=22) curve at ^{50}Ni have high separation energy than its neighbor one since it have Z= 28 magic number.
Furthermore, the two-proton separation of double magic nuclei (number magic proton and neutron) is some what greater than that of non-magic nuclei. For instance as shown in the Figure 4.6 cyan colored (N=28) curve, the two-proton separation energy of double magic nuclei ^{56}Ni transit to ^{54}Fe is higher than S_{2p} of the ^{55}Ni transit to ^{53}Fe. The two-protons separation energy from doubly magic nuclei to non-magic nuclei greater than the two-proton separation energy from magic nuclei to non- magic nuclei. Two-proton separation energies exhibit jumps when crossing magic proton numbers. The magnitude of this jump is a measure of the proton magic shell gap for a given neutron number.

In Figure 4.6, The variation in results for the two-protons separation energy also provides important information with regard to the two-proton drip-line. And also the proton number Z is increased for a fixed neutron number N, the S_{2p} decreases until it becomes negative whereby we reach the unbound nucleus or the two-proton drip-line.

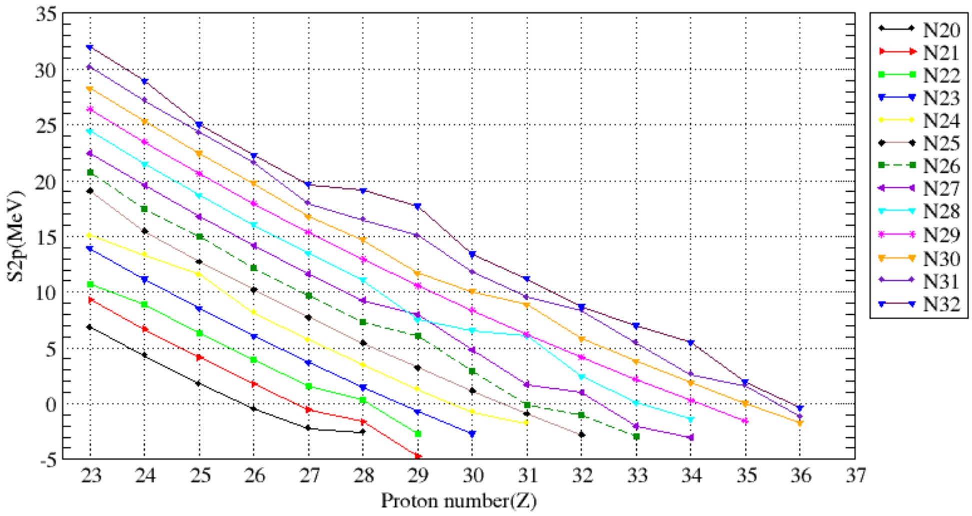

Figure 4.6: Two proton separation energy as a function of Z for different N values.

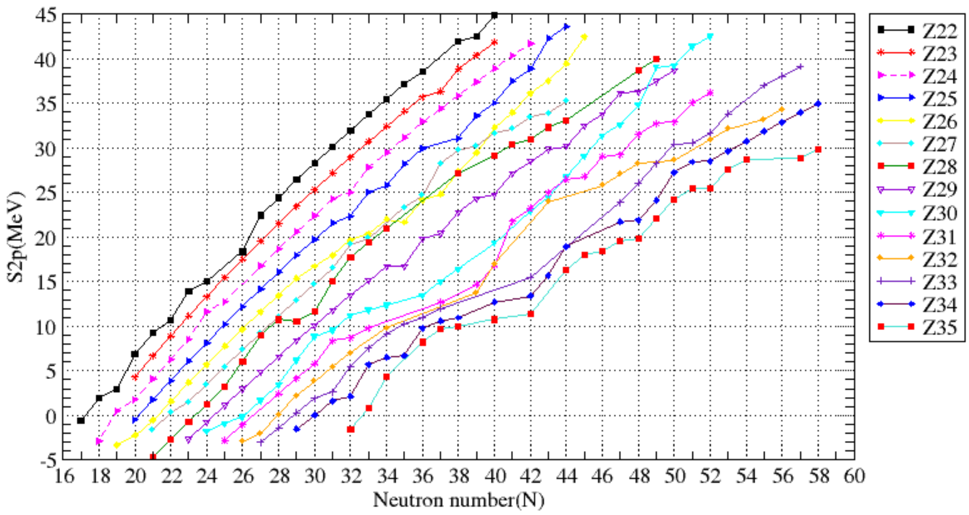

Figure 4.7: Two proton separation energy as a function of N for different Z values.

4.3.2 Two proton separation energy for fixed proton number

This section discussion Figure 4.7 shows that when the number of proton is constant (Z= 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, and 35) the two protons separation energy increases as a function of neutron number, specifically it increases starting from negative to some positive values the way of left to right. This is because of that, the nucleus rich in proton initially below the straight drip line (negative area).

In the Figure 4.7, the result of this work shows that the two-proton separation energy of transitional isotopes increases as the number of neutrons increase with in the nucleus. The Coulomb force of repulsion between the protons becomes large. In order to compensate the large repulsion force there has to be greater number of neutrons. This is due to the contribution of neutrons for stability of the nucleus with in the same nucleus.

Thus two proton separation energy shows discontinuity at different point as neutron number is increases. We can readily understand that in medium heavy nuclei the Coulomb repulsion will favor a neutron-proton distribution with more neutrons than protons.

And also in the Figure 4.7 we can see that the sharp increasing of two-proton separation energy at magic number of either proton or neutron. For instance Scandium-42 having N=20 and Scandium-50 having N=28 the black colored (Z=22) curve have higher two-proton separation energy than the neighbor isotopes. Similarly Nickel-56 the in the middle green colored (Z=28) curve have high two-proton separation energy because of its characteristics of double magic N=28 and Z=28. In addition there is also sharp increasing of two-proton separation energy on three consecutive isotopes of Z=33, 34 and 35, since their neutron is 50 magic number.

4.3.3 Two Neutron Separation Energy for fixed Proton Number

Here the discussion is on Figure 4.8, that we were calculated two-neutron separation energy for fixed proton for varying neutron number. For any fixed number of protons, S_{2n} decreases smoothly as the number of neutron increases. This is because of the symmetry term goes to high for the increasing the difference between the number of proton and the number of neutron, the term is favored for A = 2Z.

For two neutron separation energy, we notice a steady decline in separation energy with increase in neutron number. The evolution of S_{2n}, as a function of neutron number, shows the well-known regularities for any fixed number of protons, S_{2n} decreases smoothly as the number of neutron increases. This decrease mostly has sharp discontinuities at neutron spherical closures magic numbers 20, 28, and 50, i.e. the energy necessary to remove two neutrons from non-magic nuclei is much smaller than that to remove two neutrons from the magic nuclei , and much smaller than is expected from the regular smooth trend. For instance the black colored (Z=20) curve the two neutron separation energy of ^{40}Ca is 28 MeV , and at the middle cyan colored (Z=28) for ^{56}Ni is 30 MeV, therefore they have high separation energies than neighbor isotopes since they are double magic nuclei. In addition to this on the right of graph green colored (Z= 35) curve, ^{85}Br have high value of two neutron separation energy than the next Bromine isotopes since it has neutron magic number 50. They indicate very clearly the major shell closures at neutron magic number reflected by strong discontinuities of S_{2n} as a function of neutron number.

4.3.4 Two neutron separation energy for fixed neutron number

Under this section Figure 4.9 were plotted as functions of Z while N was kept constant N= 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, and 32. It provides information of Two-neutron separation energies for the neutron-rich nuclei of the isotonic transitions. We can see here two neutron separation energy were calculated for fixed isotone for varying proton number. In Figure 4.9 two neutron separation energy increases as proton number increase for fixed neutron number. If we add more neutrons, they will have to be more energetic, thus increasing the total energy of the nucleus. There fore asymmetry energy term have high effect to make the nucleus have relatively large stability. It can be more easily understood by considering the fact that this term goes to zero for A = 2Z and its effect is smaller for larger A (while for smaller nuclei the symmetry effect is

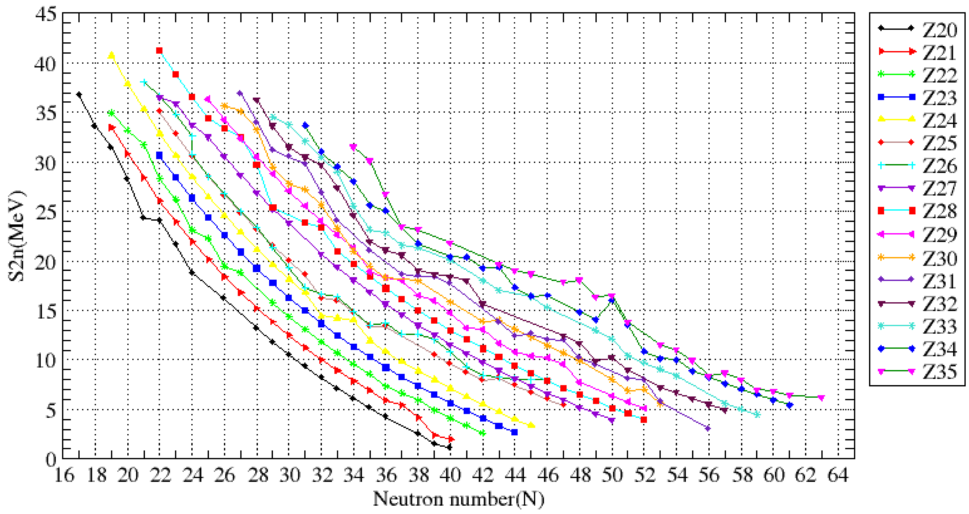

Figure 4.8: Two neutron separation energy as a function of N for different Z values.

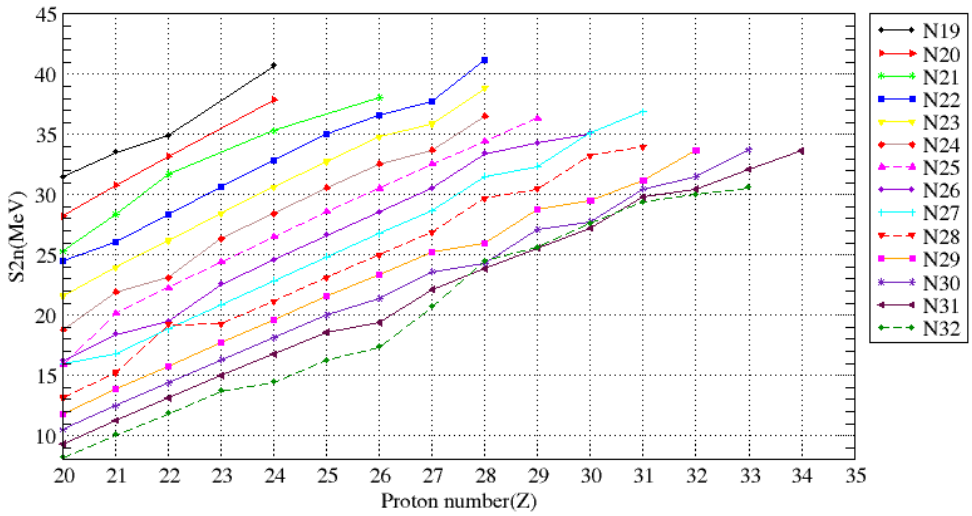

Figure 4.9: Two neutron separation energy as a function of Z for different N values.

more important).

As shown in Figure 4.9 we can get another information,there is sharp increasing of two neutron separation energy observed at ^{50}Ti and ^{60}Ni, since they have N = 28 and Z = 28, magic number respectively.

4.4 Nucleon Separation Energy and Nuclear Stability in the region 20 $\leq$ Z $\leq$ 35

For stable nuclides having atomic number $Z < 20$, N=Z or A=2Z, but for $Z > 20$ the number of neutrons has to be greater than Z for stability of the nucleus. As the result of this work shown that, the behavior of nucleon separation energy depends on different factors. From these factors nucleon number plays a great role. But the effect of proton and neutron with in the nucleus is not the same in all cases. The proton is highly related to the Coulombs effect due to its positive charge. Since Coulombs effect affects the stability of the nucleus, the nucleon separation energy decreases as the proton number is greater than neutron numbers in some nuclei.

In case of considering the magic nuclei, the most of magic nuclei are highly bound and more stable than the nuclei nearby it. Hence, nuclear stability and nucleon separation energy has a relationship. Some times as proton or/and neutron separation energy increases, the stability of the nucleus also increases.

The stability of nuclei is of great interest because unstable nuclei undergo transitions that result in the emission of particles. In the area of this study, we know that in Binding energy per nucleon for Iron (Fe) and Nickel (Ni) has the highest binding energy per nucleon so is the most stable nucleus. Practically, separating nucleons is very essential. For instance removing one proton from ^{57}Co and ^{63}Cu will give us ^{56}Fe and ^{62}Ni respectively, since ^{56}Fe and ^{62}Ni are very stable and having 8.8 MeV Binding energy per nucleon. The energy spend in removing nucleons from a system of identical nucleus shows system stability, which means a nuclei having high separation energy are highly stable and abundant.

5

Conclusion and Recommendation

In this work, the results of Investigation of One and Two Nucleon Separation Energies for Checking the Nuclear Stability have been performed for isotopes of Atomic number between 20 and 35. From the above analysis we find that the separation energy plays a very important role in understanding the nuclear stability.
Single proton separation energy increases as the neutron number of the given isotope increase for fixed proton. That means additional neutrons requires to assure nuclear stability. A single neutron separation energy not follow the same pattern with one proton separation energy, rather it fluctuate depending on the evenness and oddness of the nucleon numbers of the nuclei as described pairing term. Because of this the maximum (up) peaks have even neutron while minimum (down) peaks have odd neutron number. single proton separation energy along the line of isotones decrease by increasing protons, because asymmetry and Coulomb term reduces the binding energy.
Two proton separation energy decreases as a function of proton number for fixed neutron. Due to increasing of proton number the mass number, A will be large. In case of the increasing of the difference between the number of proton and number of neutron the effect of asymmetry energy term become high then the separation energy decreased. Two-neutron separation energy provides information on the neutron-rich nuclei of the isotonic transitions. Two neutron separation energy increases as proton number increase for fixed neutron number. There fore asymmetry energy term have small value to make the nucleus have relatively large stability.

The one and two nucleon separation energies used to get more fundamental properties of the atomic nucleus such as isotopic and isotopic transitions. The magic number nuclei are not only highly stable but shows additional characteristics which are greater relative abundances in nature, greater number of stable isotopes, large value of nucleon separation energy and so on. Generally, The energy spend in removing nucleons from a system of identical nucleus shows system stability, which means a nuclei having high separation energy are highly stable and abundant.

We have seen that it is possible to plot and discuss two nucleon separation energies such as two neutron separation energy(S_{2n}) and two proton separation energy(S_{2p}) as a function of either neutron or proton for fixed nucleon number. Which means we have discussed S_{2p} as a function of N for fixed Z and vice versa. And also S_{2n} as a function of Z for fixed N and vice versa. But here we can not have plots and discussion for separation energy of such two nucleon(i.e 1P + 1N) as a function of Z for fixed N, or two nucleon (i.e 1N + 1P) as a function of N for fixed Z. There fore for future the researcher should calculate and check it for further studies.

Table 5.1: Calculated value of Binding Energy of Isotopes of atomic number between 20 and 35 and their separation energies.

Calcium	Z	N	A	BE(MeV) [Calc'd]	S_n(MeV)	S_{2n}(MeV)	S_p(MeV)	S_{2p}(MeV)
^{35}Ca	20	15	35	259.45498	-	-	-0.43141	-1.44376
^{36}Ca	20	16	36	280.61864	21.163660	-	2.3053	1.93469
^{37}Ca	20	17	37	296.19542	15.576780	36.740440	3.66913	4.76298
^{38}Ca	20	18	38	314.25827	18.062850	33.639630	4.94777	7.41216
^{39}Ca	20	19	39	327.68050	12.822230	31.485080	6.84735	10.69944
^{40}Ca	20	20	40	342.50143	15.420930	28.243160	8.46507	14.61545
^{41}Ca	20	21	41	352.97427	10.472840	25.293770	10.69958	19.1618
^{42}Ca	20	22	42	366.97427	13.151700	24.472840	14.70445	23.99405
^{43}Ca	20	23	43	374.57969	8.4537200	21.605420	14.0267	24.95491
^{44}Ca	20	24	44	385.76800	11.188310	18.793730	16.12349	27.21088
^{45}Ca	20	25	45	390.47452	6.7065200	15.894830	14.23235	25.48866
^{46}Ca	20	26	46	401.94276	9.4782400	16.174760	16.26164	27.61237
^{47}Ca	20	27	47	407.13789	5.1951300	16.663370	15.32166	28.77561
^{48}Ca	20	28	48	415.11767	7.9797800	13.174910	15.30622	28.79359
^{49}Ca	20	29	49	418.97051	3.8528400	11.832620	15.30061	29.12961
^{50}Ca	20	30	50	425.62997	6.6594600	10.512300	16.23342	30.7387
^{51}Ca	20	31	51	428.31002	2.6800500	9.3395100	14.57546	30.66486
^{52}Ca	20	32	52	433.80021	5.4901900	8.1702400	15.05958	31.47189
^{53}Ca	20	33	53	435.44290	1.6426900	7.13288	13.95251	32.29536
^{54}Ca	20	34	54	439.89274	4.4498400	6.0925300	15.59098	33.00699
^{55}Ca	20	35	55	440.61384	0.7211000	5.1709400	20.63796	33.73466
^{56}Ca	20	36	56	444.13399	3.5201500	4.2412500	16.43367	-
^{57}Ca	20	37	57	446.03399	1.9000000	5.4201500	16.2387	-
^{58}Ca	20	38	58	446.71904	0.6850500	2.5850500	-	-

^{59}Ca	20	39	59	446.88191	0.1628700	0.8479200	-	-
^{60}Ca	20	40	60	447.81680	0.9348900	1.0977600	-	-
Scandium								
^{38}Sc	21	17	38	294.58806	-	-	-1.60736	2.06177
^{39}Sc	21	18	39	313.94489	19.35683	-	-0.31338	4.63439
^{40}Sc	21	19	40	328.08148	14.13659	33.49342	0.40098	7.24833
^{41}Sc	21	20	41	344.73813	16.65665	30.79324	2.2367	10.70177
^{42}Sc	21	21	42	356.46291	11.72478	28.38143	3.48864	14.18822
^{43}Sc	21	22	43	370.79142	14.32851	26.05329	3.81715	18.5216
^{44}Sc	21	23	44	380.43534	9.64392	23.97243	5.85565	19.88235
^{45}Sc	21	24	45	392.74247	12.30713	21.95105	6.97447	23.09796
^{46}Sc	21	25	46	400.57924	7.83677	20.1439	10.10472	24.33707
^{47}Sc	21	26	47	411.12021	10.54097	18.37774	9.17745	25.43909
^{48}Sc	21	27	48	417.37817	6.25796	16.79893	10.24028	25.56194
^{49}Sc	21	28	49	426.36703	8.98886	15.24682	11.24936	26.55558
^{50}Sc	21	29	50	431.23811	4.87108	13.85994	12.2676	27.56821
^{51}Sc	21	30	51	438.85571	7.6176	12.48868	13.22574	29.45916
^{52}Sc	21	31	52	442.50242	3.64671	11.26431	14.1924	28.76786
^{53}Sc	21	32	53	448.90262	6.4002	10.04691	15.10241	30.16199
^{54}Sc	21	33	54	451.46342	2.5608	8.961	16.02052	29.97303
^{55}Sc	21	34	55	456.77795	5.31453	7.87533	16.88521	32.47619
^{56}Sc	21	35	56	458.37155	1.5936	6.90813	17.75771	38.39567
^{57}Sc	21	36	57	462.71384	4.34229	5.93589	18.57985	35.01352
^{58}Sc	21	37	58	464.44257	1.72873	6.07102	18.40858	34.64728
^{59}Sc	21	38	59	466.91082	2.46825	4.19698	20.19178	
^{60}Sc	21	39	60	466.86335	-0.04747	2.42078	19.98144	
^{61}Sc	21	40	61	469.54301	2.67966	2.63219	21.72621	

Titanium	Z	N	A	BE(MeV) [Calc'd]	S_n(MeV)	S_{2n}(MeV)	S_p(MeV)	S_{2p}(MeV)
^{39}Ti	22	17	39	295.62952	-	-	1.04146	-0.5659
^{40}Ti	22	18	40	316.19380	20.56428	-	2.24891	1.93553
^{41}Ti	22	19	41	330.56140	14.3676	34.93188	2.47992	2.8809
^{42}Ti	22	20	42	349.37696	18.81556	33.18316	4.63883	6.87553
^{43}Ti	22	21	43	362.27968	12.90272	31.71828	5.81677	9.30541
^{44}Ti	22	22	44	377.71671	15.43703	28.33975	6.92529	10.74244
^{45}Ti	22	23	45	388.48497	10.76826	26.20529	8.04963	13.90528
^{46}Ti	22	24	46	400.85011	12.36514	23.1334	8.10764	15.08211
^{47}Ti	22	25	47	410.75841	9.9083	22.27344	10.17917	18.28389
^{48}Ti	22	26	48	420.30702	9.54861	19.45691	9.18681	18.36426
^{49}Ti	22	27	49	429.58610	9.27908	18.82769	12.20793	22.44821
^{50}Ti	22	28	50	439.53543	9.94933	19.22841	13.1684	24.41776
^{51}Ti	22	29	51	445.37771	5.84228	15.79161	14.1396	26.4072
^{52}Ti	22	30	52	453.90982	8.53211	14.37439	15.05411	28.27985
^{53}Ti	22	31	53	458.48091	4.57109	13.1032	15.97849	30.17089
^{54}Ti	22	32	54	465.75188	7.27097	11.84206	16.84926	31.95167
^{55}Ti	22	33	55	469.19268	3.4408	10.71177	17.72926	33.74978
^{56}Ti	22	34	56	475.33651	6.14383	9.58463	18.55856	35.44377
^{57}Ti	22	35	57	477.76818	2.43167	8.5755	19.39663	37.15434
^{58}Ti	22	36	58	482.70059	4.93241	7.36408	19.98675	38.5666
^{59}Ti	22	37	59	484.42786	1.72727	6.65968	19.98529	38.39387
^{60}Ti	22	38	60	488.64929	4.22143	5.9487	21.73847	41.93025
^{61}Ti	22	39	61	489.36316	0.71387	4.9353	22.49981	42.48125
^{62}Ti	22	40	62	492.76120	3.39804	4.11191	23.21819	44.9444
^{63}Ti	22	41	63	492.74109	- 0.02011	3.37793	-	-
^{64}Ti	22	42	64	495.39250	2.65141	2.6313	-	-

Vanadium	Z	N	A	BE(MeV) [Calc'd]	S_n(MeV)	S_{2n}(MeV)	S_p(MeV)	S_{2p}(MeV)
^{43}V	23	20	43	349.04448	-	-	-0.33248	4.30635
^{44}V	23	21	44	363.13959	14.09511	-	0.85991	6.67668
^{45}V	23	22	45	379.70202	16.56243	30.65754	1.98531	8.9106
^{46}V	23	23	46	391.61093	11.90891	28.47134	3.12596	11.17559
^{47}V	23	24	47	406.05250	14.44157	26.35048	5.20239	13.31003
^{48}V	23	25	48	416.05020	9.9977	24.43927	5.29179	15.47096
^{49}V	23	26	49	428.62774	12.57754	22.57524	8.32072	17.50753
^{50}V	23	27	50	436.94548	8.31774	20.89528	7.35938	19.56731
^{51}V	23	28	51	447.87601	10.93053	19.24827	8.34058	21.50898
^{52}V	23	29	52	454.70961	6.8336	17.76413	9.3319	23.4715
^{53}V	23	30	53	464.17777	9.46816	16.30176	10.26795	25.32206
^{54}V	23	31	54	469.69416	5.51639	14.98455	11.21325	27.19174
^{55}V	23	32	55	477.85801	8.16385	13.68024	12.10613	28.95539
^{56}V	23	33	56	482.20032	4.34231	12.50616	13.00764	30.7369
^{57}V	23	34	57	489.19600	6.99568	11.33799	13.85949	32.41805
^{58}V	23	35	58	492.48768	3.29168	10.28736	14.7195	34.11613
^{59}V	23	36	59	498.43302	5.94534	9.23702	15.73243	35.71918
^{60}V	23	37	60	500.78106	2.34804	8.29338	16.3532	36.33849
^{61}V	23	38	61	505.77864	4.99758	7.34562	17.12935	38.86782
^{62}V	23	39	62	507.27623	1.49759	6.49517	17.91307	40.41288
^{63}V	23	40	63	511.41569	4.13946	5.63705	18.65449	41.87268
^{64}V	23	41	64	512.14437	0.72868	4.86814	19.40328	-
^{65}V	23	42	65	515.50444	3.36007	4.08875	20.11194	-
^{66}V	23	43	66	515.53585	0.03141	3.39148	-	-
^{67}V	23	44	67	518.18593	2.65008	2.68149	-	-

Chromium	Z	N	A	BE(MeV) [Calc'd]	S_n(MeV)	S_{2n}(MeV)	S_p(MeV)	S_{2p}(MeV)
^{41}Cr	24	17	41	290.38618	-	-	-	-3.24334
^{42}Cr	24	18	42	313.31009	22.92391	-	-	-2.88371
^{43}Cr	24	19	43	331.08583	17.77574	40.69965	-	0.52443
^{44}Cr	24	20	44	351.17652	20.09069	37.86643	2.13204	1.79956
^{45}Cr	24	21	45	366.39393	15.21741	35.3081	3.25434	4.11425
^{46}Cr	24	22	46	384.01613	17.6222	32.83961	4.31411	6.29942
^{47}Cr	24	23	47	397.00246	12.98633	30.60853	5.39153	8.51749
^{48}Cr	24	24	48	412.46172	15.45926	28.44559	6.40922	11.61161
^{49}Cr	24	25	49	423.49194	11.03022	26.48948	7.44174	12.73353
^{50}Cr	24	26	50	437.04471	13.55277	24.58299	8.41697	16.73769
^{51}Cr	24	27	51	446.35062	9.30591	22.85868	9.40514	16.76452
^{52}Cr	24	28	52	458.21460	11.86398	21.16989	10.33859	18.67917
^{53}Cr	24	29	53	465.99320	7.7786	19.64258	11.28359	20.61549
^{54}Cr	24	30	54	476.35421	10.36101	18.13961	12.17644	22.44439
^{55}Cr	24	31	55	482.77394	6.41973	16.78074	13.07978	24.29303
^{56}Cr	24	32	56	490.79154	8.0176	14.43733	12.93353	25.03966
^{57}Cr	24	33	57	496.99730	6.20576	14.22336	14.79698	27.80462
^{58}Cr	24	34	58	504.80925	7.81195	14.01771	15.61325	29.47274
^{59}Cr	24	35	59	508.92631	4.11706	11.92901	16.43863	31.15813
^{60}Cr	24	36	60	515.65223	6.72592	10.84298	17.21921	32.95164
^{61}Cr	24	37	61	518.78947	3.13724	9.86316	18.00841	34.36161
^{62}Cr	24	38	62	524.53366	5.74419	8.88143	18.75502	35.88437
^{63}Cr	24	39	63	526.78613	2.25247	7.99666	19.5099	37.42297
^{64}Cr	24	40	64	531.64000	4.85387	7.10634	20.22431	38.8788
^{65}Cr	24	41	65	533.09107	1.45107	6.30494	20.9467	40.34998
^{66}Cr	24	42	66	537.13504	4.04397	5.49504	21.6306	41.74254
^{67}Cr	24	43	67	537.85810	0.72306	4.76703	22.32225	-

^{68}Cr	24	44	68	541.16321	3.30511	4.02817	22.97728	-
^{69}Cr	24	45	69	541.22314	0.05993	3.36504	-	-
Manganese								
^{45}Mn	25	20	45	348.55979	-	-	-2.61673	-0.48469
^{46}Mn	25	21	46	364.91128	16.35149	-	-1.48265	1.77169
^{47}Mn	25	22	47	383.60831	18.69703	35.04852	-0.40782	3.90629
^{48}Mn	25	23	48	397.68598	14.07767	32.7747	0.68352	6.07505
^{49}Mn	25	24	49	414.17870	16.49272	30.57039	1.71698	8.1262
^{50}Mn	25	25	50	426.25666	12.07796	28.57068	2.76472	10.20646
^{51}Mn	25	26	51	440.80153	14.54487	26.62283	3.75682	12.17379
^{52}Mn	25	27	52	451.11197	10.31044	24.85531	4.76135	14.16649
^{53}Mn	25	28	53	463.92720	12.81523	23.12567	5.7126	16.05119
^{54}Mn	25	29	54	472.66808	8.74088	21.55611	6.67488	17.95847
^{55}Mn	25	30	55	483.94049	11.27241	20.01329	7.58628	19.76272
^{56}Mn	25	31	56	491.28161	7.34112	18.61353	8.50767	21.58745
^{57}Mn	25	32	57	500.17207	8.89046	16.23158	9.38053	22.31406
^{58}Mn	25	33	58	507.25990	7.08783	15.97829	10.2626	25.05958
^{59}Mn	25	34	59	515.00772	7.74782	14.83565	10.19847	25.81172
^{60}Mn	25	35	60	520.66923	5.66151	13.40933	11.74292	28.18155
^{61}Mn	25	36	61	528.39563	7.7264	13.38791	12.7434	29.96261
^{62}Mn	25	37	62	530.34146	1.94583	9.67223	11.55199	29.5604
^{63}Mn	25	38	63	536.85240	6.51094	8.45677	12.31874	31.07376
^{64}Mn	25	39	64	540.87937	4.02697	10.53791	14.09324	33.60314
^{65}Mn	25	40	65	546.46791	5.58854	9.61551	14.82791	35.05222
^{66}Mn	25	41	66	549.66112	3.19321	8.78175	16.57005	37.51675

^{67}Mn	25	42	67	554.40930	4.74818	7.94139	17.27426	38.90486
^{68}Mn	25	43	68	557.84382	3.43452	8.1827	19.98572	42.30797
^{69}Mn	25	44	69	561.82426	3.98044	7.41496	20.66105	43.63833
^{70}Mn	25	45	70	566.56658	4.74232	8.72276	25.34344	-
^{71}Mn	25	46	71	569.84379	3.27721	8.01953	-	-
^{72}Mn	25	47	72	571.95300	2.10921	5.38642	-	-
Iron								
^{45}Ir	26	19	45	327.80050	-	-	-	-3.28533
^{46}Ir	26	20	46	348.95082	21.15032	-	0.39103	-2.2257
^{47}Ir	26	21	47	365.87004	16.91922	38.06954	0.95876	-0.52389
^{48}Ir	26	22	48	385.57938	19.70934	36.62856	1.97107	1.56325
^{49}Ir	26	23	49	400.68801	15.10863	34.81797	3.00203	3.68555
^{50}Ir	26	24	50	418.15779	17.46978	32.57841	3.97909	5.69607
^{51}Ir	26	25	51	431.22874	13.07095	30.54073	4.97208	7.7368
^{52}Ir	26	26	52	446.71453	15.48579	28.55674	5.913	9.66982
^{53}Ir	26	27	53	457.97977	11.26524	26.75103	6.8678	11.62915
^{54}Ir	26	28	54	471.69972	13.71995	24.98519	7.77252	13.48512
^{55}Ir	26	29	55	481.35763	9.65791	23.37786	8.68955	15.36443
^{56}Ir	26	30	56	493.09907	11.74144	21.39935	9.15858	16.74486
^{57}Ir	26	31	57	500.72034	7.62127	19.36271	9.43873	17.9464
^{58}Ir	26	32	58	510.44503	9.72469	17.34596	10.27296	19.65349
^{59}Ir	26	33	59	517.37726	6.93223	16.65692	10.11736	20.37996
^{60}Ir	26	34	60	526.82563	9.44837	16.3806	11.81791	22.01638
^{61}Ir	26	35	61	530.59713	3.7715	13.21987	9.9279	21.67082
^{62}Ir	26	36	62	539.83166	9.23453	13.00603	11.43603	24.17943
^{63}Ir	26	37	63	543.61450	3.78284	13.01737	13.27304	24.82503
^{64}Ir	26	38	64	551.86250	8.248	12.03084	15.0101	27.32884
^{65}Ir	26	39	65	556.23497	4.37247	12.62047	15.3556	29.44884

^{66}Ir	26	40	66	563.93088	7.69591	12.06838	17.46297	32.29088
^{67}Ir	26	41	67	567.03953	3.10865	10.80456	17.37841	33.94846
^{68}Ir	26	42	68	573.26679	6.22726	9.33591	18.85749	36.13175
^{69}Ir	26	43	69	575.38816	2.12137	8.34863	17.54434	37.53006
^{70}Ir	26	44	70	580.62074	5.23258	7.35395	18.79648	39.45753
^{71}Ir	26	45	71	583.72272	3.10198	8.33456	17.15614	42.49958
^{72}Ir	26	46	72	589.32645	5.60373	8.70571	19.48266	-
^{73}Ir	26	47	73	591.96950	2.64305	8.24678	20.0165	-
^{74}Ir	26	48	74	589.30316	-2.66634	-0.02329	-	-
^{75}Ir	26	49	75	589.44127	0.13811	-2.52823	-	-
Cobalt								
^{47}Co	27	20	47	347.78765	-	-	-1.16317	-0.77214
^{48}Co	27	21	48	363.28552	15.49787	-	-2.58452	-1.62576
^{49}Co	27	22	49	383.91989	20.63437	36.13224	-1.65949	0.31158
^{50}Co	27	23	50	399.17165	15.25176	35.88613	-1.51636	1.48567
^{51}Co	27	24	51	417.63226	18.46061	33.71237	-0.52553	3.45356
^{52}Co	27	25	52	431.70948	14.07722	32.53783	0.48074	5.45282
^{53}Co	27	26	53	448.15091	16.44143	30.51865	1.43638	7.34938
^{54}Co	27	27	54	460.38518	12.23427	28.6757	2.40541	9.27321
^{55}Co	27	28	55	475.02539	14.64021	26.87448	3.32567	11.09819
^{56}Co	27	29	56	485.61540	10.59001	25.23022	4.25777	12.94732
^{57}Co	27	30	57	498.64208	13.02668	23.61669	5.54301	14.70159
^{58}Co	27	31	58	507.75923	9.11715	22.14383	7.03889	16.47762
^{59}Co	27	32	59	519.33492	11.57569	20.69284	8.88989	19.16285
^{60}Co	27	33	60	527.12786	7.79294	19.36863	9.7506	19.86796
^{61}Co	27	34	61	537.39397	10.26611	18.05905	10.56834	22.38625
^{62}Co	27	35	62	543.99223	6.59826	16.86437	13.3951	23.323
^{63}Co	27	36	63	553.07243	9.0802	15.67846	13.24077	24.6768

^{64}Co	27	37	64	558.58938	5.51695	14.59715	14.97488	28.24792
^{65}Co	27	38	65	566.59224	8.00286	13.51981	14.72974	29.73984
^{66}Co	27	39	66	571.12754	4.5353	12.53816	14.89257	30.24817
^{67}Co	27	40	67	578.14881	7.02127	11.55657	14.21793	31.6809
^{68}Co	27	41	68	581.79043	3.64162	10.66289	14.7509	32.12931
^{69}Co	27	42	69	587.91483	6.1244	9.76602	14.64804	33.50553
^{70}Co	27	43	70	590.74068	2.82585	8.95025	15.35252	32.89686
^{71}Co	27	44	71	596.04351	5.30283	8.12868	15.42277	34.21925
^{72}Co	27	45	72	598.12283	2.07932	7.38215	14.40011	31.55625
^{73}Co	27	46	73	602.67119	4.54836	6.62768	13.34474	32.8274
^{74}Co	27	47	74	604.06575	1.39456	5.94292	12.09625	32.11275
^{75}Co	27	48	75	607.91963	3.85388	5.24844	18.61647	-
^{76}Co	27	49	76	608.68469	0.76506	4.61894	19.24342	-
^{77}Co	27	50	77	611.89793	3.21324	3.9783	-	-
Nickel								
^{48}Ni	28	20	48	341.66080	-	-	-3.12685	-5.29002
^{49}Ni	28	21	49	361.17433	19.51353	-	-2.11119	-4.69571
^{50}Ni	28	22	50	382.87468	21.70035	41.21388	-1.04521	-2.7047
^{51}Ni	28	23	51	400.01209	17.13741	38.83776	0.84044	-0.67592
^{52}Ni	28	24	52	419.40962	19.39753	36.53494	1.77736	1.25183
^{53}Ni	28	25	53	434.44062	15.031	34.42853	2.73114	3.21188
^{54}Ni	28	26	54	452.78842	18.3478	33.3788	4.63751	6.07389
^{55}Ni	28	27	55	466.94375	14.15533	32.50313	6.55857	8.96398
^{56}Ni	28	28	56	482.45912	15.51537	29.6707	7.43373	10.7594
^{57}Ni	28	29	57	491.93730	9.47818	24.99355	6.3219	10.57967
^{58}Ni	28	30	58	504.80792	12.87062	22.3488	6.16584	11.70885
^{59}Ni	28	31	59	515.78070	10.97278	23.8434	8.02147	15.06036
^{60}Ni	28	32	60	528.16948	12.38878	23.36156	8.83456	17.72445

^{61}Ni	28	33	61	536.78615	8.61667	21.00545	9.65829	19.40889
^{62}Ni	28	34	62	547.83519	11.04904	19.66571	10.44122	21.00956
^{63}Ni	28	35	63	555.22618	7.39099	18.44003	11.23395	24.62905
^{64}Ni	28	36	64	565.06	9.83382	17.22481	11.98757	25.22834
^{65}Ni	28	37	65	571.33972	6.27972	16.11354	12.75034	27.72522
^{66}Ni	28	38	66	580.06789	8.72817	15.00789	13.47565	28.20539
^{67}Ni	28	39	67	585.33712	5.26923	13.9974	14.20958	29.10215
^{68}Ni	28	40	68	593.05643	7.71931	12.98854	14.90762	29.12555
^{69}Ni	28	41	69	597.40429	4.34786	12.06717	15.61386	30.36476
^{70}Ni	28	42	70	604.20059	6.7963	11.14416	16.28576	30.9338
^{71}Ni	28	43	71	607.70616	3.50557	10.30187	16.96548	32.318
^{72}Ni	28	44	72	613.65584	5.94968	9.45525	17.61233	33.0351
^{73}Ni	28	45	73	616.38954	2.7337	8.68338	18.26671	32.66682
^{74}Ni	28	46	74	621.56080	5.17126	7.90496	18.88961	32.23435
^{75}Ni	28	47	75	623.58555	2.02475	7.19601	19.5198	31.61605
^{76}Ni	28	48	76	628.03947	4.45392	6.47867	20.11984	38.73631
^{77}Ni	28	49	77	629.41163	1.37216	5.82608	20.72694	39.97036
^{78}Ni	28	50	78	633.20308	3.79145	5.16361	21.30515	-
^{79}Ni	28	51	79	633.97331	0.77023	4.56168	-	-
^{80}Ni	28	52	80	637.15172	3.17841	3.94864	-	-
Copper								
^{52}Cu	29	23	52	396.50215	-	-	-3.50994	-2.6695
^{53}Cu	29	24	53	416.84891	20.34676	-	-2.56071	-0.78335
^{54}Cu	29	25	54	432.84548	15.99657	36.34333	-1.59514	1.136
^{55}Cu	29	26	55	451.11271	18.26723	34.2638	-1.67571	2.9618
^{56}Cu	29	27	56	465.20170	7 14.08899	32.35622	-1.74205	4.81652
^{57}Cu	29	28	57	481.60601	16.40431	30.4933	-0.85311	6.58062

^{58}Cu	29	29	58	493.98568	12.37967	28.78398	2.04838	8.37028
^{59}Cu	29	30	59	508.71460	14.72892	27.10859	3.90668	10.07252
^{60}Cu	29	31	60	519.55694	10.84234	25.57126	3.77624	11.79771
^{61}Cu	29	32	61	532.77367	13.21673	24.05907	4.60419	13.43875
^{62}Cu	29	33	62	542.22853	9.45486	22.67159	5.44238	15.10067
^{63}Cu	29	34	63	554.07577	11.84724	21.3021	6.24058	16.6818
^{64}Cu	29	35	64	560.72438	6.64861	18.49585	5.4982	16.73215
^{65}Cu	29	36	65	572.87742	12.15304	18.80165	7.81742	19.80499
^{66}Cu	29	37	66	579.03512	6.1577	18.31074	7.6954	20.44574
^{67}Cu	29	38	67	589.40446	10.36934	16.52704	9.33657	22.81222
^{68}Cu	29	39	68	595.42309	6.01863	16.38797	10.08597	24.29555
^{69}Cu	29	40	69	602.85651	7.43342	13.45205	9.80008	24.7077
^{70}Cu	29	41	70	608.92628	6.06977	13.50319	11.52199	27.13585
^{71}Cu	29	42	71	616.41067	7.48439	13.55416	12.21008	28.49584
^{72}Cu	29	43	72	620.61177	4.2011	11.68549	12.90561	29.87109
^{73}Cu	29	44	73	626.22457	5.6128	9.8139	12.56873	30.18106
^{74}Cu	29	45	74	630.62855	4.40398	10.01678	14.23901	32.50572
^{75}Cu	29	46	75	636.43901	5.81046	10.21444	14.87821	33.76782
^{76}Cu	29	47	76	640.19987	3.76086	9.57132	16.61432	36.13412
^{77}Cu	29	48	77	644.18012	3.98025	7.74111	16.14065	36.26049
^{78}Cu	29	49	78	646.17532	1.9952	5.97545	16.76369	37.49063
^{79}Cu	29	50	79	650.56124	4.38592	6.38112	17.35816	38.66331
^{80}Cu	29	51	80	651.93246	1.37122	5.75714	17.95915	-
^{81}Cu	29	52	81	655.68446	3.752	5.12322	18.53274	-
^{82}Cu	29	53	82	665.47836	9.7939	13.5459	-	-
Zinc								
^{54}Zn	30	24	54	417.62030	-	-	0.77139	-1.78932
^{55}Zn	30	25	55	433.53228	15.91198	-	0.6868	-0.90834

^{56}Zn	30	26	56	452.67168	19.1394	35.05138	1.55897	-0.11674
^{57}Zn	30	27	57	468.64819	15.97651	35.11591	3.44649	1.70444
^{58}Zn	30	28	58	485.89793	17.24974	33.22625	4.29192	3.43881
^{59}Zn	30	29	59	498.13663	12.2387	29.48844	4.15095	6.19933
^{60}Zn	30	30	60	513.68378	15.54715	27.78585	4.96918	8.87586
^{61}Zn	30	31	61	525.35653	11.67275	27.2199	5.79959	9.57583
^{62}Zn	30	32	62	539.36426	14.00773	25.68048	6.59059	11.19478
^{63}Zn	30	33	63	548.62119	9.25693	23.26466	6.39266	11.83504
^{64}Zn	30	34	64	560.23250	11.61131	20.86824	6.15673	12.39731
^{65}Zn	30	35	65	566.20533	5.97283	17.58414	5.48095	10.97915
^{66}Zn	30	36	66	578.54605	12.34072	18.31355	5.66863	13.48605
^{67}Zn	30	37	67	586.35084	7.80479	20.14551	7.31572	15.01112
^{68}Zn	30	38	68	596.53212	10.18128	17.98607	7.12766	16.46423
^{69}Zn	30	39	69	607.27152	10.7394	20.92068	11.84843	21.9344
^{70}Zn	30	40	70	612.39194	5.12042	15.85982	9.53543	19.33551
^{71}Zn	30	41	71	618.15704	5.7651	10.88552	9.23076	20.75275
^{72}Zn	30	42	72	626.30433	8.14729	13.91239	9.89366	22.10374
^{73}Zn	30	43	73	632.17627	5.87194	14.01923	11.5645	24.47011
^{74}Zn	30	44	74	640.42876	8.25249	14.12443	14.20419	26.77292
^{75}Zn	30	45	75	645.48002	5.05126	13.30375	14.85147	29.09048
^{76}Zn	30	46	76	652.90786	7.42784	12.4791	16.46885	31.34706
^{77}Zn	30	47	77	656.20341	3.29555	10.72339	16.00354	32.61786
^{78}Zn	30	48	78	662.86963	6.66622	9.96177	18.68951	34.83016
^{79}Zn	30	49	79	668.46785	5.59822	12.26444	22.29253	39.05622
^{80}Zn	30	50	80	672.42921	3.96136	9.55958	21.86797	39.22613
^{81}Zn	30	51	81	675.38272	2.95351	6.91487	23.45026	41.40941
^{82}Zn	30	52	82	679.69051	4.30779	7.2613	24.00605	42.53879

^{83}Zn	30	53	83	680.94685	1.25634	5.56413	15.46849	-
^{84}Zn	30	54	84	681.74749	0.80064	2.05698	-	-
^{85}Zn	30	55	85	686.54973	4.80224	5.60288	-	-
^{86}Zn	30	56	86	689.68537	3.13564	7.93788	-	-
Gallium								
^{56}Ga	31	25	56	430.04051	-	-	-3.49177	-2.80497
^{57}Ga	31	26	57	450.06386	20.02335	-	-2.60782	-1.04885
^{58}Ga	31	27	58	466.93925	16.87539	36.89874	-1.70894	1.73755
^{59}Ga	31	28	59	484.04679	17.10754	33.98293	-1.85114	2.44078
^{60}Ga	31	29	60	498.15647	14.10968	31.21722	0.01984	4.17079
^{61}Ga	31	30	61	514.53473	16.37826	30.48794	0.85095	5.82013
^{62}Ga	31	31	62	527.95037	12.51564	29.7939	2.59384	8.39343
^{63}Ga	31	32	63	541.46244	14.81207	26.92771	2.09818	8.68877
^{64}Ga	31	33	64	552.03438	11.07194	24.08401	3.41319	9.80585
^{65}Ga	31	34	65	562.32346	13.38908	20.86102	2.09096	8.24769
^{66}Ga	31	35	66	573.08386	9.760400	21.04948	6.87853	12.35948
^{67}Ga	31	36	67	584.17626	11.0924	21.8528	5.63021	11.29884
^{68}Ga	31	37	68	591.74181	7.56555	18.65795	5.39097	12.70669
^{69}Ga	31	38	69	610.12338	8.47408	18.38157	2.85186	14.70029
^{70}Ga	31	39	70	610.12338	8.47408	18.38157	2.85186	14.70029
^{71}Ga	31	40	71	619.64527	9.52189	17.99597	7.25333	16.78876
^{72}Ga	31	41	72	631.99982	12.35455	21.87644	13.84278	23.07354
^{73}Ga	31	42	73	640.24464	8.24482	20.59937	13.94031	23.83397
^{74}Ga	31	43	74	645.80167	5.55703	13.80185	13.6254	25.1899
^{75}Ga	31	44	75	652.70857	6.9069	12.46393	12.2798	26.484
^{76}Ga	31	45	76	657.42148	4.71291	11.61981	11.94146	26.79293
^{77}Ga	31	46	77	665.48149	8.06001	12.77292	12.57363	29.04248
^{78}Ga	31	47	78	669.41615	3.93466	11.99467	13.21274	29.21628

^{79}Ga	31	48	79	675.69314	6.27699	10.21165	12.82351	31.51302
^{80}Ga	31	49	80	678.90885	3.21571	9.4927	10.441	32.73353
^{81}Ga	31	50	81	683.46045	4.5516	7.76731	11.03124	32.89921
^{82}Ga	31	51	82	687.01071	3.55026	8.10186	11.62799	35.07825
^{83}Ga	31	52	83	691.88904	4.87833	8.42859	12.19853	36.20458
^{84}Ga	31	53	84	692.82226	1.93322	5.81155	11.87541	27.3439
^{85}Ga	31	54	85	701.07458	4.25232	9.18554	19.32709	-
^{86}Ga	31	55	86	702.43466	1.36008	9.6124	15.88493	-
^{87}Ga	31	56	87	704.10390	3.66924	3.02932	14.41853	-
^{88}Ga	31	57	88	705.93075	0.82685	3.49609	-	-
Germanium								
^{58}Ge	32	26	58	449.71505	-	-	-0.34881	-2.95663
^{59}Ge	32	27	59	466.64507	16.93002	-	-0.29418	-2.00312
^{60}Ge	32	28	60	485.96854	19.32347	36.25349	1.92175	0.07061
^{61}Ge	32	29	61	500.30826	14.33972	33.66319	2.15179	2.17163
^{62}Ge	32	30	62	517.47887	17.17061	31.51033	2.94414	3.79509
^{63}Ge	32	31	63	530.79952	13.32065	30.49126	2.84915	5.44299
^{64}Ge	32	32	64	546.38000	15.58048	28.90113	4.91756	7.01574
^{65}Ge	32	33	65	556.23181	9.85181	25.43229	4.19743	7.61062
^{66}Ge	32	34	66	570.06536	13.83355	23.68536	7.7419	9.83286
^{67}Ge	32	35	67	580.88072	10.81536	24.64891	7.79686	14.67539
^{68}Ge	32	36	68	591.99387	11.11315	21.92851	7.81761	13.44782
^{69}Ge	32	37	69	601.98986	9.99599	21.10914	10.24805	15.63902
^{70}Ge	32	38	70	612.59480	10.60494	20.60093	10.9455	16.06268
^{71}Ge	32	39	71	620.99537	8.40057	19.00551	10.87199	13.72385
^{72}Ge	32	40	72	631.27195	10.27658	18.67715	11.62668	18.88001
^{73}Ge	32	41	73	640.42968	9.15773	19.43431	8.42986	22.27264

^{74}Ge	32	42	74	649.90705	9.47737	18.6351	9.66241	23.60272
^{75}Ge	32	43	75	655.12468	5.21763	14.695	9.32301	22.94841
^{76}Ge	32	44	76	661.66269	6.53801	11.75564	8.95412	21.23393
^{77}Ge	32	45	77	667.01436	5.35167	11.88968	9.59288	21.53434
^{78}Ge	32	46	78	678.68474	11.67038	17.02205	13.20325	25.77688
^{79}Ge	32	47	79	683.23712	4.55238	16.22276	13.82097	27.03371
^{80}Ge	32	48	80	691.10449	7.86737	12.41975	15.41135	28.23486
^{81}Ge	32	49	81	694.91764	3.81315	11.68052	16.00879	26.44979
^{82}Ge	32	50	82	701.04038	6.12274	9.93589	17.57993	28.61117
^{83}Ge	32	51	83	704.16859	3.12821	9.25095	17.15788	28.78587
^{84}Ge	32	52	84	710.59954	6.43095	9.55916	18.7105	30.90903
^{85}Ge	32	53	85	713.09199	2.49245	8.9234	20.26973	32.14514
^{86}Ge	32	54	86	717.87915	4.78716	7.27961	16.80457	36.13166
^{87}Ge	32	55	87	719.78049	1.90134	6.6885	17.34583	33.23076
^{88}Ge	32	56	88	723.96749	4.187	6.08834	19.86359	34.28212
^{89}Ge	32	57	89	725.31836	1.35087	5.53787	19.38761	-
^{90}Ge	32	58	90	728.94501	3.62665	4.97752	-	-
Arsenic								
^{60}As	33	27	60	463.92645	-	-	-2.71862	-3.0128
^{61}As	33	28	61	482.67713	18.75068	-	-3.29141	-1.36966
^{62}As	33	29	62	498.45775	15.78062	34.5313	-1.85051	0.30128
^{63}As	33	30	63	516.43242	17.97467	33.75529	-1.04645	1.89769
^{64}As	33	31	64	530.56938	14.13696	32.11163	-0.23014	2.61901
^{65}As	33	32	65	546.93036	16.36098	30.49794	0.55036	5.46792
^{66}As	33	33	66	559.57376	12.6434	29.00438	3.34195	7.53938
^{67}As	33	34	67	572.46421	12.89045	25.53385	2.39885	10.14075
^{68}As	33	35	68	582.74658	10.28237	23.17282	1.86586	9.66272
^{69}As	33	36	69	595.29319	12.54661	22.82898	3.29932	11.11693

^{70}As	33	37	70	604.33199	9.0388	21.58541	2.34213	12.59018
^{71}As	33	38	71	616.64732	12.31533	21.35413	4.05252	14.99802
^{72}As	33	39	72	627.54699	10.89967	23.215	6.55162	14.42361
^{73}As	33	40	73	637.73140	10.18441	21.08408	6.45945	16.08613
^{74}As	33	41	74	643.58512	5.85372	16.03813	5.15544	16.5853
^{75}As	33	42	75	655.72833	12.14321	17.99693	5.82128	15.48369
^{76}As	33	43	76	660.61952	4.89119	17.0344	5.49484	16.81785
^{77}As	33	44	77	670.80203	10.18251	15.0737	9.13934	18.09346
^{78}As	33	45	78	677.00555	6.20352	16.38603	9.99119	19.58407
^{79}As	33	46	79	686.09977	9.09422	15.29774	9.41503	20.61828
^{80}As	33	47	80	693.28302	7.18325	16.27747	10.0459	23.86687
^{81}As	33	48	81	701.75429	8.47127	15.65452	10.6498	26.06115
^{82}As	33	49	82	707.17809	5.4238	13.89507	12.26045	28.26924
^{83}As	33	50	83	713.88549	6.7074	12.1312	12.84511	30.42504
^{84}As	33	51	84	717.60488	3.71939	10.42679	13.43629	30.59417
^{85}As	33	52	85	723.60198	5.9971	9.71649	13.00244	31.71294
^{86}As	33	53	86	726.66689	3.06491	9.06201	13.5749	33.84463
^{87}As	33	54	87	732.00236	5.33547	8.40038	14.12321	30.92778
^{88}As	33	55	88	739.45816	7.4558	12.79127	19.67767	37.0235
^{89}As	33	56	89	742.17635	2.71819	10.17399	18.20886	38.07245
^{90}As	33	57	90	745.06440	2.88805	5.60624	19.74604	39.13365
^{91}As	33	58	91	747.20578	2.14138	5.02943	18.26077	-
^{92}As	33	59	92	749.56381	2.35803	4.49941	-	-
Selenium								
^{63}Se	34	29	63	498.76116	-	-	0.30341	-1.5471
^{64}Se	34	30	64	517.5025	18.74134	-	1.07008	0.02363

^{65}Se	34	31	65	532.41914	14.91664	33.65798	1.84976	1.61962
^{66}Se	34	32	66	548.52584	16.1067	31.02334	1.59548	2.14584
^{67}Se	34	33	67	561.92674	13.4009	29.5076	2.35298	5.69493
^{68}Se	34	34	68	576.54167	14.61493	28.01583	4.07746	6.47631
^{69}Se	34	35	69	587.55930	11.01763	25.63256	4.81272	6.67858
^{70}Se	34	36	70	601.80916	14.24986	25.26749	6.51597	9.81529
^{71}Se	34	37	71	612.56114	10.75198	25.00184	8.22915	10.57128
^{72}Se	34	38	72	623.55867	12.99753	21.74951	6.91135	10.96387
^{73}Se	34	39	73	631.14978	9.591110	18.58864	3.60279	10.15441
^{74}Se	34	40	74	643.99566	11.84588	20.43699	6.26426	12.72371
^{75}Se	34	41	75	651.51953	8.523870	20.36975	7.93441	11.08985
^{76}Se	34	42	76	663.30393	10.78440	19.30827	7.5756	13.39688
^{77}Se	34	43	77	670.84449	7.54056	19.32496	10.22497	15.71981
^{78}Se	34	44	78	680.64842	9.80393	17.34449	9.84639	18.98573
^{79}Se	34	45	79	687.28112	6.6327	16.43663	10.27557	20.26676
^{80}Se	34	46	80	697.17756	8.89644	16.52914	11.07779	18.49282
^{81}Se	34	47	81	704.97041	7.79285	17.68929	11.68739	21.73329
^{82}Se	34	48	82	712.02528	8.054870	14.84772	10.27099	20.92079
^{83}Se	34	49	83	719.03975	5.01447	14.06934	11.86166	24.12211
^{84}Se	34	50	84	728.31274	7.27299	16.28746	14.42725	27.27236
^{85}Se	34	51	85	732.60454	4.2918	13.56479	14.99966	28.43595
^{86}Se	34	52	86	738.14983	5.54529	9.83709	14.54785	27.55029
^{87}Se	34	53	87	742.76951	4.01968	10.16497	16.10262	29.67752
^{88}Se	34	54	88	748.63640	5.06689	10.48657	16.63404	30.75725
^{89}Se	34	55	89	751.63001	2.99361	8.8605	12.17185	31.84952

^{90}Se	34	56	90	756.86345	5.00344	8.22705	14.6871	32.89596
^{91}Se	34	57	91	759.27296	2.40951	7.64295	14.20856	33.9546
^{92}Se	34	58	92	763.91403	4.64107	7.05058	16.70825	34.96902
^{93}Se	34	59	93	765.77780	1.86377	6.50484	16.21399	-
^{94}Se	34	60	94	769.86411	4.08631	5.95008	-	-
^{95}Se	34	61	95	771.21728	1.35317	5.43948	-	-
Bromine								
^{65}Br	35	30	65	514.69812	-	-	-2.80438	-1.7343
^{66}Br	35	31	66	529.40482	15.70670	-	-3.01432	-1.16456
^{67}Br	35	32	67	545.26830	15.86348	30.57018	-3.25754	-1.66206
^{68}Br	35	33	68	560.43741	14.169110	31.03259	-1.48933	0.86365
^{69}Br	35	34	69	576.78819	16.35078	31.51989	0.24652	4.32398
^{70}Br	35	35	70	590.55210	13.76391	30.11469	2.9928	7.80552
^{71}Br	35	36	71	603.51682	14.96472	26.72863	1.70766	8.22363
^{72}Br	35	37	72	613.99328	11.476460	23.44118	1.43214	9.66129
^{73}Br	35	38	73	626.68484	12.69156	23.16802	3.12617	10.03752
^{74}Br	35	39	74	634.97890	10.29406	20.98562	3.82912	7.43191
^{75}Br	35	40	75	648.49827	12.519370	21.81343	4.50261	10.76687
^{76}Br	35	41	76	657.70398	9.20571	22.72508	6.18445	14.11886
^{77}Br	35	42	77	667.14174	9.43776	18.64347	3.83781	11.41341
^{78}Br	35	43	78	676.34351	9.00177	18.63953	5.49902	15.72399
^{79}Br	35	44	79	687.08114	10.73763	19.9394	6.43272	16.27911
^{80}Br	35	45	80	695.05498	7.97384	18.71147	7.77386	18.04943
^{81}Br	35	46	81	703.56599	9.51101	16.48485	6.38843	17.46622
^{82}Br	35	47	82	712.90051	6.41452	17.84553	7.9301	19.61749
^{83}Br	35	48	83	721.63138	8.65087	18.06539	9.6061	19.87709
^{84}Br	35	49	84	729.24866	5.61728	16.34815	10.20891	22.07057

^{85}Br	35	50	85	738.09966	7.85100	16.46828	9.78692	24.21417
^{86}Br	35	51	86	743.07602	4.87636	13.82736	10.47148	25.47114
^{87}Br	35	52	87	749.08194	7.10592	10.98228	10.93211	25.47996
^{88}Br	35	53	88	754.26858	4.18664	11.19256	11.49907	27.60169
^{89}Br	35	54	89	760.67932	6.01074	11.59738	12.04292	28.67696
^{90}Br	35	55	90	764.22289	3.54357	9.95431	12.59288	24.76473
^{91}Br	35	56	91	769.08399	4.8611	8.40467	12.22054	26.90764
^{92}Br	35	57	92	772.92709	3.3431	8.7042	13.65413	27.86269
^{93}Br	35	58	93	777.08021	4.15312	7.99622	13.16618	29.87443
^{94}Br	35	59	94	779.46182	2.38161	6.53473	13.68402	29.89801
^{95}Br	35	60	95	783.04514	3.58332	5.96493	13.18103	-
^{96}Br	35	61	96	785.90096	2.05582	6.43914	14.68368	-
^{97}Br	35	62	97	790.94953	3.04857	7.90439	-	-
^{98}Br	35	63	98	792.31238	1.36285	6.41142	-	-

[Note: All energies are in mega electron-volt(MeV)].

Table 5.2: Transitions of atomic number between 20 and 35 and their neutron separation energies

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
18	^{38}Ca to ^{37}Ca	18.06285	-	-
18	^{39}Sc to ^{38}Sc	19.35683	-	-
18	^{40}Ti to ^{39}Ti	20.56428	-	-
18	^{42}Cr to ^{41}Cr	22.92391	-	-
19	^{39}Ca to ^{38}Ca	13.42223	^{39}Ca to ^{37}Ca	31.48508
19	^{40}Sc to ^{39}Sc	14.13659	^{40}Sc to ^{38}Sc	33.49342
19	^{41}Ti to ^{40}Ti	14.3676	^{41}Ti to ^{39}Ti	34.93188
19	^{43}Cr to ^{42}Cr	17.77574	^{43}Cr to ^{41}Cr	40.69965
20	^{40}Ca to ^{39}Ca	14.82093	^{40}Ca to ^{38}Ca	28.24316
20	^{41}Sc to ^{40}Sc	16.65665	^{41}Sc to ^{39}Sc	30.79324
20	^{42}Ti to ^{41}Ti	18.81556	^{42}Ti to ^{40}Ti	33.18316
20	^{44}Cr to^{43}Cr	20.09069	^{44}Cr to ^{42}Cr	37.86643
20	^{46}Fe to ^{45}Fe	21.15032	-	-
21	^{41}Ca to ^{40}Ca	10.47284	^{41}Ca to ^{39}Ca	25.29377
21	^{42}Sc to ^{41}Sc	11.72478	^{42}Sc to ^{40}Sc	28.38143
21	^{43}Ti to ^{42}Ti	12.90272	^{43}Ti to ^{41}Ti	31.71828
21	^{44}V to ^{43}V	14.09511	-	-
21	^{45}Cr to ^{44}Cr	15.21741	^{45}Cr to ^{43}Cr	35.3081
21	^{46}Mn to ^{45}Mn	16.35149	-	-
21	^{47}Fe to ^{46}Fe	16.91922	^{47}Fe to ^{45}Fe	38.06954
21	^{48}Co to ^{47}Co	15.49787	-	-
21	^{49}Ni to ^{48}Ni	19.51353	-	-

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
22	^{42}Ca to ^{41}Ca	14	^{42}Ca to ^{40}Ca	24.47284
22	^{43}Sc to ^{42}Sc	14.32851	^{43}Sc to ^{41}Sc	26.05329
22	^{44}Ti to ^{43}Ti	15.43703	^{44}Ti to ^{42}Ti	28.33975
22	^{45}V to ^{44}V	16.56243	^{45}V to ^{43}V	30.65754
22	^{46}Cr to ^{45}Cr	17.6222	^{46}Cr to ^{44}Cr	32.83961
22	^{47}Mn to ^{46}Mn	18.69703	^{47}Mn to ^{45}Mn	35.04852
22	^{48}Fe to ^{47}Fe	19.70934	^{48}Fe to ^{46}Fe	36.62856
22	^{49}Co to ^{48}Co	20.63437	^{49}Co to ^{47}Co	36.13224
22	^{50}Ni to ^{49}Ni	21.70035	^{50}Ni to ^{48}Ni	41.21388
23	^{43}Ca to ^{42}Ca	7.60542	^{43}Ca to ^{41}Ca	21.60542
23	^{44}Sc to ^{43}Sc	9.64392	^{44}Sc to ^{42}Sc	23.97243
23	^{45}Ti to ^{44}Ti	10.76826	^{45}Ti to ^{43}Ti	26.20529
23	^{46}V to ^{45}V	11.90891	^{46}V to ^{44}V	28.47134
23	^{47}Cr to ^{46}Cr	12.98633	^{47}Cr to ^{45}Cr	30.60853
23	^{48}Mn to ^{47}Mn	14.07767	^{48}Mn to ^{46}Mn	32.7747
23	^{49}Fe to ^{48}Fe	15.10863	^{49}Fe to ^{47}Fe	34.81797
23	^{50}Co to ^{49}Co	15.25176	^{50}Co to ^{48}Co	35.88613
23	^{51}Ni to ^{50}Ni	17.13741	^{51}Ni to ^{49}Ni	38.83776
24	^{44}Ca to ^{43}Ca	11.188310	^{44}Ca to ^{42}Ca	18.793730
24	^{45}Sc to ^{44}Sc	12.30713	^{45}Sc to ^{43}Sc	21.95105
24	^{46}Ti to ^{45}Ti	12.36514	^{46}Ti to ^{44}Ti	23.1334
24	^{47}V to ^{46}V	14.44157	^{47}V to ^{45}V	26.35048
24	^{48}Cr to ^{47}Cr	15.45926	^{48}Cr to ^{46}Cr	28.44559
24	^{49}Mn to ^{48}Mn	16.49272	^{49}Mn to ^{47}Mn	30.57039

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
24	^{50}Fe to ^{49}Fe	17.46978	^{50}Fe to ^{48}Fe	32.57841
24	^{51}Co to ^{50}Co	18.46061	^{51}Co to ^{49}Co	33.71237
24	^{52}Ni to ^{51}Ni	19.39753	^{52}Ni to ^{50}Ni	36.53494
24	^{53}Cu to ^{52}Cu	20.34676	-	-
25	^{45}Ca to ^{44}Ca	4.7065200	^{45}Ca to ^{43}Ca	15.894830
25	^{46}Sc to ^{45}Sc	7.83677	^{46}Sc to ^{44}Sc	20.1439
25	^{47}Ti to ^{46}Ti	9.9083	^{47}Ti to ^{45}Ti	22.27344
25	^{48}V to ^{47}V	9.9977	^{48}V to ^{46}V	24.43927
25	^{49}Cr to ^{48}Cr	11.03022	^{49}Cr to ^{47}Cr	26.48948
25	^{50}Mn to ^{49}Mn	12.07796	^{50}Mn to ^{48}Mn	28.57068
25	^{51}Fe to ^{50}Fe	13.07095	^{51}Fe to ^{49}Fe	30.54073
25	^{52}Co to ^{51}Co	14.07722	^{52}Co to ^{50}Co	32.53783
25	^{53}Ni to ^{52}Ni	15.031	^{53}Ni to ^{51}Ni	34.42853
25	^{54}Cu to ^{53}Cu	15.99657	^{54}Cu to ^{52}Cu	36.34333
25	^{55}Zn to ^{54}Zn	15.91198	-	-
26	^{46}Ca to ^{45}Ca	11.468240	^{46}Ca to ^{44}Ca	16.174760
26	^{47}Sc to ^{46}Sc	10.54097	^{47}Sc to ^{45}Sc	18.37774
26	^{48}Ti to ^{47}Ti	9.54861	^{48}Ti to ^{46}Ti	19.45691
26	^{49}V to ^{48}V	12.57754	^{49}V to ^{47}V	22.57524
26	^{50}Cr to ^{49}Cr	13.55277	^{50}Cr to ^{48}Cr	24.58299
26	^{51}Mn to ^{50}Mn	14.54487	51Mn to ^{49}Mn	26.62283
26	^{52}Fe to ^{51}Fe	15.48579	^{52}Fe to ^{50}Fe	28.55674
26	^{53}Co to ^{52}Co	16.44143	^{53}Co to ^{51}Co	30.51865
26	^{54}Ni to ^{53}Ni	18.3478	^{54}Ni to ^{52}Ni	33.3788
26	^{55}Cu to ^{54}Cu	18.26723	^{55}Cu to ^{53}Cu	34.2638

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
26	^{56}Zn to ^{55}Zn	19.1394	^{56}Zn to ^{54}Zn	35.05138
26	^{57}Ga to ^{56}Ga	20.02335	-	-
27	^{47}Ca to ^{46}Ca	5.1951300	^{47}Ca to ^{45}Ca	16.663370
27	^{48}Sc to ^{47}Sc	6.25796	^{48}Sc to ^{46}Sc	16.79893
27	^{49}Ti to ^{48}Ti	9.27908	^{49}Ti to ^{47}Ti	18.82769
27	^{50}V to ^{49}V	8.31774	^{50}V to ^{48}V	20.89528
27	^{51}Cr to ^{50}Cr	9.30591	^{51}Cr to ^{49}Cr	22.85868
27	^{52}Mn to ^{51}Mn	10.31044	^{52}Mn to ^{50}Mn	24.85531
27	^{53}Fe to ^{52}Fe	11.26524	53Fe to 51Fe	26.75103
27	^{54}Co to ^{53}Co	12.23427	^{54}Co to ^{52}Co	28.6757
27	^{55}Ni to ^{54}Ni	14.15533	^{55}Ni to ^{53}Ni	32.50313
27	^{56}Cu to ^{55}Cu	14.08899	^{56}Cu to ^{54}Cu	32.35622
27	^{57}Zn to ^{56}Zn	15.97651	^{57}Zn to ^{55}Zn	35.11591
27	^{58}Ga to ^{57}Ga	16.87539	^{58}Ga to ^{56}Ga	36.89874
27	^{59}Ge to ^{58}Ge	16.93002	-	-
28	^{48}Ca to ^{47}Ca	7.9797800	^{48}Ca to ^{46}Ca	13.174910
28	^{49}Sc to ^{48}Sc	8.98886	^{49}Sc to ^{47}Sc	15.24682
28	^{50}Ti to ^{49}Ti	9.94933	^{50}Ti to ^{48}Ti	19.22841
28	^{51}V to ^{50}V	10.93053	^{51}V to ^{49}V	19.24827
28	^{52}Cr to ^{51}Cr	11.86398	^{52}Cr to ^{50}Cr	21.16989
28	^{53}Mn to ^{52}Mn	12.81523	^{53}Mn to ^{51}Mn	23.12567
28	^{54}Fe to ^{53}Fe	13.71995	^{54}Fe to ^{52}Fe	24.98519
28	^{55}Co to ^{54}Co	14.64021	^{55}Co to ^{53}Co	26.87448
28	^{56}Ni to ^{55}Ni	15.51537	^{56}Ni to ^{54}Ni	29.6707

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
28	^{57}Cu to ^{56}Cu	16.40431	^{57}Cu to ^{55}Cu	30.4933
28	^{58}Zn to ^{57}Zn	17.24974	^{58}Zn to ^{56}Zn	33.22625
28	^{59}Ga to ^{58}Ga	17.10754	^{59}Ga to ^{57}Ga	33.98293
28	^{60}Ge to ^{59}Ge	19.32347	-	-
29	^{49}Ca to ^{48}Ca	3.8528400	^{49}Ca to ^{47}Ca	11.832620
29	^{50}Sc to ^{49}Sc	4.87108	^{50}Sc to ^{48}Sc	13.85994
29	^{51}Ti to ^{50}Ti	5.84228	^{51}Ti to ^{49}Ti	15.79161
29	^{52}V to ^{51}V	6.8336	^{52}V to ^{50}V	17.76413
29	^{53}Cr to ^{52}Cr	7.7786	^{53}Cr to ^{51}Cr	19.64258
29	^{54}Mn to ^{53}Mn	8.74088	^{54}Mn to ^{52}Mn	21.55611
29	^{55}Fe to ^{54}Fe	9.65791	^{55}Fe to ^{53}Fe	23.37786
29	^{56}Co to ^{55}Co	10.59001	^{56}Co to ^{54}Co	25.23022
29	^{57}Ni to ^{56}Ni	9.47818	^{57}Ni to ^{55}Ni	24.99355
29	^{58}Cu to ^{57}Cu	12.37967	^{58}Cu to ^{56}Cu	28.78398
29	^{59}Zn to ^{58}Zn	12.2387	^{59}Zn to ^{57}Zn	29.48844
29	^{60}Ga to ^{59}Ga	14.10968	^{60}Ga to ^{58}Ga	31.21722
29	^{61}Ge to ^{60}Ge	14.33972	^{61}Ge to ^{59}Ge	33.66319
29	^{62}As to ^{61}As	15.78062	-	-
30	^{50}Ca to ^{49}Ca	6.6594600	^{50}Ca to ^{48}Ca	10.512300
30	^{51}Sc to ^{50}Sc	7.6176	^{51}Sc to ^{49}Sc	12.48868
30	^{52}Ti to ^{51}Ti	8.53211	^{52}Ti to ^{50}Ti	14.37439
30	^{53}V to ^{52}V	9.46816	^{53}V to ^{51}V	16.30176
30	^{54}Cr to ^{53}Cr	10.36101	^{54}Cr to ^{52}Cr	18.13961
30	^{55}Mn to ^{54}Mn	11.27241	^{55}Mn to ^{53}Mn	20.01329
30	^{56}Fe to ^{55}Fe	11.74144	^{56}Fe to ^{54}Fe	21.39935

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
30	^{57}Co to ^{56}Co	13.02668	^{57}Co to ^{55}Co	23.61669
30	^{58}Ni to ^{57}Ni	12.87062	^{58}Ni to ^{56}Ni	22.3488
30	^{59}Cu to ^{58}Cu	14.72892	^{59}Cu to ^{57}Cu	27.10859
30	^{60}Zn to ^{59}Zn	15.54715	^{60}Zn to ^{58}Zn	27.78585
30	^{61}Ga to ^{60}Ga	16.37826	^{61}Ga to ^{59}Ga	30.48794
30	^{62}Ge to ^{61}Ge	17.17061	^{62}Ge to ^{60}Ge	31.51033
30	^{63}As to ^{62}As	17.97467	^{63}As to ^{61}As	33.75529
30	^{64}Se to ^{63}Se	18.74134	-	-
31	^{51}Ca to ^{50}Ca	2.6800500	^{51}Ca to ^{49}Ca	9.3395100
31	^{52}Sc to ^{51}Sc	3.64671	^{52}Sc to ^{50}Sc	11.26431
31	^{53}Ti to ^{52}Ti	4.57109	^{53}Ti to ^{51}Ti	13.1032
31	^{54}V to ^{53}V	5.51639	^{54}V to ^{52}V	14.98455
31	^{55}Cr to ^{54}Cr	6.41973	^{55}Cr to ^{53}Cr	16.78074
31	^{56}Mn to ^{55}Mn	7.34112	^{56}Mn to ^{54}Mn	18.61353
31	^{57}Fe to ^{56}Fe	7.62127	^{57}Fe to ^{55}Fe	19.36271
31	^{58}Co to ^{57}Co	9.11715	^{58}Co to ^{56}Co	22.14383
31	^{59}Ni to ^{58}Ni	10.97278	^{59}Ni to ^{57}Ni	23.8434
31	^{60}Cu to ^{59}Cu	10.84234	^{60}Cu to ^{58}Cu	25.57126
31	^{61}Zn to ^{60}Zn	11.67275	^{61}Zn to ^{59}Zn	27.2199
31	^{62}Ga to ^{61}Ga	13.41564	^{62}Ga to ^{60}Ga	29.7939
31	^{63}Ge to ^{62}Ge	13.32065	^{63}Ge to ^{61}Ge	30.49126
31	^{64}As to ^{63}As	14.13696	^{64}As to ^{62}As	32.11163
31	^{65}Se to ^{64}Se	14.91664	^{65}Se to ^{63}Se	33.65798
31	^{66}Br to ^{65}Br	14.7067	-	-

N	Transition	S_n(MeV)	Transition	S_{2n}(MeV)
32	^{52}Ca to ^{51}Ca	5.4901900	^{52}Ca to ^{50}Ca	8.1702400
32	^{53}Sc to ^{52}Sc	6.4002	^{53}Sc to ^{51}Sc	10.04691
32	^{54}Ti to ^{53}Ti	7.27097	^{54}Ti to ^{52}Ti	11.84206
32	^{55}V to ^{54}V	8.16385	^{55}V to ^{53}V	13.68024
32	^{56}Cr to ^{55}Cr	8.0176	^{56}Cr to ^{54}Cr	14.43733
32	^{57}Mn to ^{56}Mn	8.89046	^{57}Mn to ^{55}Mn	16.23158
32	^{58}Fe to ^{57}Fe	9.72469	^{58}Fe to ^{56}Fe	17.34596
32	^{59}Co to ^{58}Co	11.57569	^{59}Co to ^{57}Co	20.69284
32	^{60}Ni to ^{59}Ni	12.38878	^{60}Ni to ^{58}Ni	23.36156
32	^{61}Cu to ^{60}Cu	13.21673	^{61}Cu to ^{59}Cu	24.05907
32	^{62}Zn to ^{61}Zn	14.00773	^{62}Zn to ^{60}Zn	25.68048
32	^{63}Ga to ^{62}Ga	13.51207	^{63}Ga to ^{61}Ga	26.92771
32	^{64}Ge to ^{63}Ge	15.58048	^{64}Ge to ^{62}Ge	28.90113
32	^{65}As to ^{64}As	16.36098	^{65}As to ^{63}As	30.49794
32	^{66}Se to ^{65}Se	16.1067	66Se to 64Se	31.02334
32	^{67}Br to^{66}Br	15.86348	^{67}Br to ^{65}Br	30.57018

Table 5.3: Isotonic transitions of atomic number between 20 and 35 and their proton separation energies

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
20	^{41}Sc to ^{40}Ca	2.2367	-	-
20	^{42}Ti to ^{41}Sc	4.63883	^{42}Ti to ^{40}Ca	6.87553
20	^{43}V to ^{42}Ti	-0.33248	^{43}V to ^{41}Sc	4.30635
20	^{44}Cr to ^{43}V	2.13204	^{44}Cr to ^{42}Ti	1.79956
20	^{45}Mn to ^{44}Cr	-2.61673	^{45}Mn to ^{43}V	-0.48469
20	^{46}Fe to ^{45}Mn	0.39103	^{46}Fe to ^{44}Cr	-2.2257
20	^{47}Co to ^{46}Fe	-1.16317	^{47}Co to ^{45}Mn	-0.77214
20	^{48}Ni to ^{47}Co	-6.12685	^{48}Ni to ^{46}Fe	-7.29002
21	^{42}Sc to ^{41}Ca	3.48864	-	-
21	^{43}Ti to ^{42}Sc	5.81677	^{43}Ti to ^{41}Ca	9.30541
21	^{44}V to ^{43}Ti	0.85991	^{44}V to ^{42}Sc	6.67668
21	^{45}Cr to ^{44}V	3.25434	^{45}Cr to ^{43}Ti	4.11425
21	^{46}Mn to ^{45}Cr	-1.48265	^{46}Mn to 44V	1.77169
21	^{47}Fe to ^{46}Mn	0.95876	^{47}Fe to ^{45}Cr	-0.52389
21	^{48}Co to ^{47}Fe	-2.58452	^{48}Co to ^{46}Mn	-1.62576
21	^{49}Ni to ^{48}Co	-2.11119	^{49}Ni to ^{47}Fe	-4.69571
22	^{43}Sc to^{42}Ca	3.81715	-	-
22	^{44}Ti to ^{43}Sc	6.92529	^{44}Ti to ^{42}Ca	10.74244
22	^{45}V to ^{44}Ti	1.98531	^{45}V to ^{43}Sc	8.9106
22	^{46}Cr to ^{45}V	4.31411	^{46}Cr to ^{44}Ti	6.29942
22	^{47}Mn to ^{46}Cr	-0.40782	^{47}Mn to ^{45}V	3.90629
22	^{48}Fe to ^{47}Mn	1.97107	^{48}Fe to ^{46}Cr	1.56325
22	^{49}Co to ^{48}Fe	-1.65949	^{49}Co to ^{47}Mn	0.31158

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
22	^{50}Ni to 49Co	-1.04521	50Ni to 48Fe	-2.7047
23	^{44}Sc to ^{43}Ca	5.85565	-	-
23	^{45}Ti to ^{44}Sc	8.04963	^{45}Ti to ^{43}Ca	13.90528
23	^{46}V to ^{45}Ti	3.12596	^{46}V to ^{44}Sc	11.17559
23	^{47}Cr to ^{46}V	5.39153	^{47}Cr to ^{45}Ti	8.51749
23	^{48}Mn to ^{47}Cr	0.68352	^{48}Mn to ^{46}V	6.07505
23	^{49}Fe to 48Mn	3.00203	49Fe to 47Cr	3.68555
23	^{50}Co to ^{49}Fe	-1.51636	^{50}Co to ^{48}Mn	1.48567
23	^{51}Ni to ^{50}Co	0.84044	^{51}Ni to ^{49}Fe	-0.67592
23	^{52}Cu to ^{51}Ni	-3.50994	^{52}Cu to ^{50}Co	-2.6695
24	^{45}Sc to ^{44}Ca	6.97447	-	-
24	^{46}Ti to ^{45}Sc	8.10764	^{46}Ti to ^{44}Ca	15.08211
24	^{47}V to ^{46}Ti	5.20239	^{47}V to ^{45}Sc	13.31003
24	^{48}Cr to ^{47}V	6.40922	^{48}Cr to ^{46}Ti	11.61161
24	^{49}Mn to ^{48}Cr	1.71698	^{49}Mn to ^{47}V	8.1262
24	^{50}Fe to ^{49}Mn	3.97909	^{50}Fe to ^{48}Cr	5.69607
24	^{51}Co to ^{50}Fe	-0.52553	^{51}Co to ^{49}Mn	3.45356
24	^{52}Ni to ^{51}Co	1.77736	^{52}Ni to ^{50}Fe	1.25183
24	^{53}Cu to ^{52}Ni	-2.56071	^{53}Cu to ^{51}Co	-0.78335
24	^{54}Zn to ^{53}Cu	0.77139	^{54}Zn to ^{52}Ni	-1.78932
25	^{46}Sc to ^{45}Ca	10.10472	-	-
25	^{47}Ti to ^{46}Sc	10.17917	^{47}Ti to ^{45}Ca	20.28389
25	^{48}V to ^{47}Ti	5.29179	^{48}V to ^{46}Sc	15.47096
25	^{49}Cr to ^{48}V	7.44174	^{49}Cr to ^{47}Ti	12.73353
25	^{50}Mn to ^{49}Cr	2.76472	^{50}Mn to ^{48}V	10.20646

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
25	^{51}Fe to ^{50}Mn	4.97208	^{51}Fe to 49Cr	7.7368
25	^{52}Co to ^{51}Fe	0.48074	^{52}Co to ^{50}Mn	5.45282
25	^{53}Ni to ^{52}Co	2.73114	^{53}Ni to ^{51}Fe	3.21188
25	^{54}Cu to ^{53}Ni	-1.59514	^{54}Cu to ^{52}Co	1.136
25	^{55}Zn to ^{54}Cu	0.6868	^{55}Zn to ^{53}Ni	-0.90834
25	^{56}Ga to ^{55}Zn	-3.49177	^{56}Ga to ^{54}Cu	-2.80497
26	^{47}Sc to ^{46}Ca	9.17745	-	-
26	^{48}Ti to ^{47}Sc	9.18681	^{48}Ti to ^{46}Ca	18.36426
26	^{49}V to ^{48}Ti	8.32072	^{49}V to ^{47}Sc	17.50753
26	^{50}Cr to ^{49}V	8.41697	^{50}Cr to ^{48}Ti	16.73769
26	^{51}Mn to ^{50}Cr	3.75682	^{51}Mn to ^{49}V	12.17379
26	^{52}Fe to ^{51}Mn	5.913	^{52}Fe to ^{50}Cr	9.66982
26	^{53}Co to ^{52}Fe	1.43638	^{53}Co to ^{51}Mn	7.34938
26	^{54}Ni to ^{53}Co	4.63751	^{54}Ni to ^{52}Fe	6.07389
26	^{55}Cu to ^{54}Ni	-1.67571	^{55}Cu to ^{53}Co	2.9618
26	^{56}Zn to ^{55}Cu	1.55897	^{56}Zn to ^{54}Ni	-0.11674
26	^{57}Ga to ^{56}Zn	-2.60782	^{57}Ga to ^{55}Cu	-1.04885
26	^{58}Ge to ^{57}Ga	-0.34881	^{58}Ge to ^{56}Zn	-2.95663
27	^{48}Sc to ^{47}Ca	10.24028	-	-
27	^{49}Ti to ^{48}Sc	12.20793	^{49}Ti to ^{47}Ca	22.44821
27	^{50}V to ^{49}Ti	7.35938	^{50}V to ^{48}Sc	19.56731
27	^{51}Cr to ^{50}V	9.40514	^{51}Cr to ^{49}Ti	16.76452
27	^{52}Mn to ^{51}Cr	4.76135	^{52}Mn to ^{50}V	14.16649
27	^{53}Fe to ^{52}Mn	6.8678	^{53}Fe to ^{51}Cr	11.62915
27	^{54}Co to ^{53}Fe	2.40541	^{54}Co to ^{52}Mn	9.27321
27	^{55}Ni to ^{54}Co	6.55857	^{55}Ni to ^{53}Fe	8.96398

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
27	^{56}Cu to ^{55}Ni	-1.74205	^{56}Cu to ^{54}Co	4.81652
27	^{57}Zn to ^{56}Cu	3.44649	^{57}Zn to ^{55}Ni	1.70444
27	^{58}Ga to ^{57}Zn	-1.70894	^{58}Ga to ^{56}Cu	1.73755
27	^{59}Ge to ^{58}Ga	-0.29418	^{59}Ge to ^{57}Zn	-2.00312
27	^{60}As to ^{59}Ge	-2.71862	^{60}As to ^{58}Ga	-3.0128
28	^{49}Sc to ^{48}Ca	11.24936	-	-
28	^{50}Ti to ^{49}Sc	13.1684	^{50}Ti to ^{48}Ca	24.41776
28	^{51}V to ^{50}Ti	8.34058	^{51}V to ^{49}Sc	21.50898
28	^{52}Cr to ^{51}V	10.33859	^{52}Cr to ^{50}Ti	18.67917
28	^{53}Mn to ^{52}Cr	5.7126	^{53}Mn to ^{51}V	16.05119
28	^{54}Fe to ^{53}Mn	7.77252	^{54}Fe to ^{52}Cr	13.48512
28	^{55}Co to ^{54}Fe	3.32567	^{55}Co to ^{53}Mn	11.09819
28	^{56}Ni to ^{55}Co	6.91191	^{56}Ni to ^{54}Fe	12.23758
28	^{57}Cu to ^{56}Ni	-0.33129	^{57}Cu to ^{55}Co	6.58062
28	^{58}Zn to ^{57}Cu	4.29192	^{58}Zn to ^{56}Ni	6.03937
28	^{59}Ga to ^{58}Zn	-1.85114	^{59}Ga to ^{57}Cu	2.44078
28	^{60}Ge to ^{59}Ga	1.92175	^{60}Ge to ^{58}Zn	0.07061
28	^{61}As to ^{60}Ge	-3.29141	^{61}As to ^{59}Ga	-1.36966
29	^{50}Sc to ^{49}Ca	12.2676	-	-
29	^{51}Ti to ^{50}Sc	14.1396	^{51}Ti to ^{49}Ca	26.4072
29	^{52}V to ^{51}Ti	9.3319	^{52}V to ^{50}Sc	23.4715
29	^{53}Cr to ^{52}V	11.28359	^{53}Cr to ^{51}Ti	20.61549
29	^{54}Mn to ^{53}Cr	6.67488	^{54}Mn to ^{52}V	17.95847
29	^{55}Fe to ^{54}Mn	8.68955	^{55}Fe to ^{53}Cr	15.36443
29	^{56}Co to ^{55}Fe	4.25777	^{56}Co to ^{54}Mn	12.94732

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
29	^{57}Ni to ^{56}Co	6.3219	^{57}Ni to ^{55}Fe	10.57967
29	^{58}Cu to ^{57}Ni	2.04838	^{58}Cu to ^{56}Co	8.37028
29	^{59}Zn to ^{58}Cu	4.15095	^{59}Zn to ^{57}Ni	6.19933
29	^{60}Ga to ^{59}Zn	0.01984	^{60}Ga to ^{58}Cu	4.17079
29	^{61}Ge to ^{60}Ga	2.15179	^{61}Ge to ^{59}Zn	2.17163
29	^{62}As to ^{61}Ge	-1.85051	^{62}As to ^{60}Ga	0.30128
29	^{63}Se to ^{62}As	0.30341	^{63}Se to ^{61}Ge	-1.5471
30	^{51}Sc to ^{50}Ca	13.22574	-	-
30	^{52}Ti to ^{51}Sc	15.05411	^{52}Ti to ^{50}Ca	28.27985
30	^{53}V to ^{52}Ti	10.26795	^{53}V to ^{51}Sc	25.32206
30	^{54}Cr to ^{53}V	12.17644	^{54}Cr to ^{52}Ti	22.44439
30	^{55}Mn to ^{54}Cr	7.58628	^{55}Mn to ^{53}V	19.76272
30	^{56}Fe to ^{55}Mn	9.15858	^{56}Fe to ^{54}Cr	16.74486
30	^{57}Co to ^{56}Fe	5.54301	^{57}Co to ^{55}Mn	14.70159
30	^{58}Ni to ^{57}Co	6.16584	^{58}Ni to ^{56}Fe	11.70885
30	^{59}Cu to ^{58}Ni	3.90668	^{59}Cu to ^{57}Co	10.07252
30	^{60}Zn to ^{59}Cu	4.96918	^{60}Zn to ^{58}Ni	8.87586
30	^{61}Ga to ^{60}Zn	0.85095	^{61}Ga to ^{59}Cu	5.82013
30	^{62}Ge to ^{61}Ga	2.94414	^{62}Ge to ^{60}Zn	3.79509
30	^{63}As to ^{62}Ge	-1.04645	^{63}As to ^{61}Ga	1.89769
30	^{64}Se to ^{63}As	1.07008	^{64}Se to ^{62}Ge	0.02363
30	^{65}Br to ^{64}Se	-2.80438	^{65}Br to ^{63}As	-1.7343
31	^{52}Sc to ^{51}Ca	14.1924	-	-
31	^{53}Ti to ^{52}Sc	15.97849	^{53}Ti to ^{51}Ca	30.17089
31	^{54}V to ^{53}Ti	11.21325	^{54}V to ^{52}Sc	27.19174
31	^{55}Cr to ^{54}V	13.07978	^{55}Cr to ^{53}Ti	24.29303

N	Isotonic Transition	S_p(MeV)	Isotonic Transition	S_{2p}(MeV)
31	^{56}Mn to ^{55}Cr	8.50767	^{56}Mn to ^{54}V	21.58745
31	^{57}Fe to ^{56}Mn	9.43873	^{57}Fe to ^{55}Cr	17.9464
31	^{58}Co to ^{57}Fe	7.03889	^{58}Co to ^{56}Mn	16.47762
31	^{59}Ni to ^{58}Co	8.02147	^{59}Ni to ^{57}Fe	15.06036
31	^{60}Cu to ^{59}Ni	3.77624	^{60}Cu to ^{58}Co	11.79771
31	^{61}Zn to ^{60}Cu	5.79959	^{61}Zn to ^{59}Ni	9.57583
31	^{62}Ga to ^{61}Zn	2.59384	^{62}Ga to ^{60}Cu	8.39343
31	^{63}Ge to ^{62}Ga	2.84915	^{63}Ge to ^{61}Zn	5.44299
31	^{64}As to ^{63}Ge	-0.23014	^{64}As to ^{62}Ga	2.61901
31	^{65}Se to ^{64}As	1.84976	^{65}Se to ^{63}Ge	1.61962
31	^{66}Br to ^{65}Se	-3.01432	^{66}Br to ^{64}As	-1.16456
32	^{53}Sc to ^{52}Ca	15.10241	-	-
32	^{54}Ti to ^{53}Sc	16.84926	^{54}Ti to ^{52}Ca	31.95167
32	^{55}V to ^{54}Ti	12.10613	^{55}V to ^{53}Sc	28.95539
32	^{56}Cr to ^{55}V	12.93353	^{56}Cr to ^{54}Ti	25.03966
32	^{57}Mn to ^{56}Cr	9.38053	^{57}Mn to ^{55}V	22.31406
32	^{58}Fe to ^{57}Mn	10.27296	^{58}Fe to ^{56}Cr	19.65349
32	^{59}Co to ^{58}Fe	8.88989	^{59}Co to ^{57}Mn	19.16285
32	^{60}Ni to ^{59}Co	8.83456	^{60}Ni to ^{58}Fe	17.72445
32	^{61}Cu to ^{60}Ni	4.60419	^{61}Cu to ^{59}Co	13.43875
32	^{62}Zn to ^{61}Cu	6.59059	^{62}Zn to ^{60}Ni	11.19478
32	^{63}Ga to ^{62}Zn	2.09818	^{63}Ga to ^{61}Cu	8.68877
32	^{64}Ge to ^{63}Ga	4.91756	^{64}Ge to ^{62}Zn	7.01574
32	^{65}As to ^{64}Ge	0.55036	^{65}As to ^{63}Ga	5.46792
32	^{66}Se to ^{65}As	1.59548	^{66}Se to ^{64}Ge	-3.96086
32	^{67}Br to ^{66}Se	-3.25754	^{67}Br to ^{65}As	-1.66206

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