THE STUDY OF NUCLEAR GROUND STATE ENERGY PER NUCLEON AS A FUNCTION OF ATOMIC MASS (A) IN THE RANGE BETWEEN A = 10 AND A = 20.

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A THESIS SUBMITTED TO JIMMA UNIVERSITY POST GRADUATE PROGRAM AT THE COLLEGE OF NATURAL SCIENCES DEPARTMENT OF PHYSICS IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE IN PHYSICS (NUCLEAR PHYSICS)

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February 2020

Acknowledgment

First and for most, deepest gratitude goes to my Advisor: Dr. Tekelemariam Tessema (PhD) for his continuous support, constructive comments and suggestions. Secondly, my heartfelt appreciation goes to my Co Advisor: Mr Shallo Fekadu (Msc) for his encouragement, guidance, critical comments and useful suggestions. Thirdly, I like to say thanks to all those help me while i was conducting this study. I also would like to thank my wife Tigist Alemu, my daughter Singiten Debela and my brother Aseffa Bekele for their moral and financial support. I also like to say thanks my best friends; Mr Wegari Negash, Lemi Jebesa, Demeke Wudu and Ahimed Ali, for his support guidance and useful suggestions. Finally, I would like to express my gratitude to all of my instructors who has supporting and helping me to come success and Jimma University, as institution for its financial support, and overall services.

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Abstract

In this work the binding energy per nucleon of isotopes with nucleon number less or equal to twenty, i.e for those isotopes which lie inside or near to the second closed shell has been calculated. The objectives of the calculation were to check the behavior of binding energy per nucleon near stable nuclei and to find a mechanism on how the binding energy per nucleon calculation could be used to predict the nuclear stability for other isotopes. In the calculation the method of liquid drop model and BeteWeiszaker formula has been employed. By putting the values for each parameter in the formula the binding energy per-nucleon for 100 isotopes has been calculated. The method was validated by comparing the calculated values with experimental values in literature for some of the isotopes at the beginning of the calculation. The method was acceptable with an error below 10%. The result of the calculation were presented in tables and graphs. From the result we have seen that if an isotope is containing even proton and even neutron numbers it has higher binding energy per nucleon than its neighboring isotopes and if it contains odd number of protons and odd number of neutrons then it has lower binding energy per nucleon compared to its neighbors. If an isotone is containing nucleon numbers such that the absolute of neutron excess attains its minimum then the isotope has larger value of binding energy per nucleon than the other. If the symmetric term is increasing the binding energy per nucleon decreases if the symmetric term is decreasing the binding energy per nucleon increases in the isotones. This is because of the cumulative effect of nucleon symmetricity and the coulomb repulsion. Generally compared with data from literature those isotopes with higher value of binding per nucleon are better stable than those having lower values.

Chapter 1

1 Introduction

1.1 Background of the Study

Nuclear physics is the study of atomic nuclei. From deuteron to uranium, there are almost 1700 species that occur naturally on earth. The main force responsible for nuclear properties comes from strong interaction. However, both weak and electromagnetic interaction also play important roles. For these reasons, nuclear physics serves as an important platform where basic properties of subatomic matter can be examined and fundamental laws of physics can be studied. The beginning of nuclear physics may be traced to the discover radioactivity in 1896 by Becquerel. Radioactivity was one of the few examples [1,2].

All nuclei are made of neutrons and protons; the two lightest members of the baryon family. Nucleons are, however, not elementary particles. Nuclei sit at the center of any atoms. Therefore, understanding them is of central importance to any discussions of microscopic physics. Whereas nuclei are composed of protons and neutrons (the nucleus is made up of neutrons and protons). The number of protons is the atomic number Z, and the mass number (A) is approximately the total number of nucleons, a collective name for protons and neutrons. Therefore; N=A-Z, where N is the number of neutrons. Therefore the nuclei are very small. An empirical formula for the size of the nuclei, which can be measured using the form factor in elastic electron-nuclei scattering [2,3].

Nucleus seem to be more complex why, because the nucleus is the core of the atom; it contains almost the entire mass of the atom. But, it occupies a very tiny component of the atom than a simple, massive, uniform sphere of positive electric charge. We currently think of the nucleus as being composed of nucleons of two kinds is called protons and neutrons. The protons is defined to be a particle that has a positive charge which is equal in magnitude to the charge on the electron. We designate the number of protons in the nucleus by Z so the charge on the nucleus is equal to Ze (Z is also equal to the atomic number of the element). A neutron, the other constituent of the nucleus, is defined as a particle that has no charge.

The nuclei also have excited states, whose energy is usually treated under the first class of properties, but whose decay is one of the types of radioactive decay. The structure of nuclei is more complex than that of the atom, and there is no center of attraction, the nucleons are held together by their mutual interactions which turn out to be very complicated in detail. Never the less, the short range of nuclear force and the Pauli exclusion principle conspire to provide an effective over all force centers for each nucleon [4].

A considerable amount of information about nuclear force and nuclear structure can be obtained from precise mass measurement. The mass difference between the actual nuclear mass and the mass of the individual nucleons is called mass defect.
According to Einstein famous equation, energy is equal is to the product of mass defect and square of speed of light, a considerable amount of information about nuclear force and nuclear structure can be obtained from precise mass measurement, the defect mass converted to the energy, called nuclear binding energy (BE). This energy is that holds the neutrons and protons together in the nucleus. It represents the work necessary to dissociate the nucleus in to separated nucleons or, conversely, the energy which would be released in to separate nucleons was assembled in to nucleons [6].
The energy, which each nucleon within the nucleus can possess is called, nuclear binding energy per nucleon. It is the share of energy each nucleon of the nucleus has. Total ground state energy is the minimum energy the nucleus can have at the ground energy level [11].

1.2 Statements of the Problem

In this thesis the nuclear ground state energy per nucleon as a function of atomic mass (A) in the range A=10 to 20 region has been studied theoretically and experimental values. Hence, the following research questions have been expected to be accessed.

- What are the binding energy per nucleon numerical values for different isotopes in their ground state ?
- Where does binding energy per nucleon (B/A) assumes maximum and minimum ?
- What are the behavior of the isotopes with relatively high or low B/A at the ground state ?
- What is the behavior of BE/A at the ground state of isotones ?

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this work was, to investigate the nuclear ground state energy per nucleon as a function of atomic mass in the range between A = 10 and 20.

1.3.2 Specific Objectives

Based on basic research questions and general objective of the study, the researcher design the following specific objectives; Therefore, this study is going to achieve the following specific objectives.

- To calculate the binding energy per nucleon numerical values for different isotopes in their ground state.
- To identify the binding energy per nucleon (B/A) maximum and minimum points.
- To determine the behavior of the isotopes with relatively high or low binding energy per nucleon at the ground state.
- To determine the behavior of binding energy per nucleon of isotones at the ground state.

1.4 Significance of the Study

This study may relevant in the following aspects:

- It gives the numerical value,the local maximum,local minimum of binding energy per nucleon for a given isotopes and isotones.
- It serves as a reference for all interested individuals and organizations.
- To compare the theoretical calculation and experimental values and check the validity.
- It may helps as a reference for other researchers.

1.5 Limitation of the Study

This study was constrained with some limitations. These are; the limitation of this current study are as follows:-

- Lack of sufficient time.
- Lack of sufficient budget.
- Lack of fast internet connection and
- Lack of recent and relevant literature's, particularly on local situation. However, it is attempts to make the study as complete as possible.

Chapter 2

2 Review of Literature

2.1 Nuclear Mass and Energy

Atomic mass (A) is the small, heavy and central part of an atom consisting of atomic mass (A) nucleon: Z proton and N neutron. Mass of the individual proton and neutrons which make up the nucleons. This nucleons is made of proton and neutrons. A proton is positive charged and inside the nucleus are essentially the same as those of free nucleons. So that nuclear structure and properties are a result of these nucleons interacting with each other [2].

We shall designate the number of neutrons in the nucleus by N. The total number of nucleons in the nucleus is given by N + Z = A. The total A is called the atomic mass number of the nucleus. It represents the depth of the energy well that the nucleus experience with in a nucleus. This indicates that when Z protons and N neutrons combine there is a release of energy. Also it follows that energy must be supplied to break a stable nucleus into its constituent nucleons [4].

Nucleus contains mainly two particles protons and neutrons. Or the nucleus composed of protons and neutrons, particles of nearly equal mass and the same intrinsic angular momentum or spin of half. The proton carries one unit of positive electric charge while the neutron has no electric charge. The term nucleon is used for either a proton or a neutron. In addition to its atomic number and mass number, a nucleus is also characterized by its size, shape, binding energy, and angular momentum and (if it is unstable) half-life. One of the best ways to determine the size of a nucleus is to scatter high-energy electrons from it [1].

The mass of the nucleon is the mass which mainly constitutes the mass of nucleus, which are the mass of the protons and neutrons within the nucleus i.e. the mass of protons and neutrons are the mass that is mainly constitutes mass of the nucleus [1]. Nuclei have certain time-independent properties such as mass, size, charge, nuclear spin (intrinsic angular momentum), and certain time dependent properties such as a radioactive decay and artificial transmutation (nuclear reaction).

Its mass is ;

$m_p = 1.67262x10^{-27}kg, m_n = 1.67493x10^{-27}kg.$

$but; 1U = 1.6605x10^{-27}kg.$

$Therefore, 1U = 931.5Mev/c^2.$

The mass of the nucleus should be given by;

$$Mass = Z_{m_p} + N_{m_n} \tag{1}$$

Where mass of the nucleus is the sum of mass of the proton and mass of the neutron. However, experiments show that the mass of the nucleus is less than the above. That is, We shall designate the difference between the computed mass and the real mass as the mass defect.

$$\Delta m = Z_{m_p} + N_{m_n} - M \tag{2}$$

Where M is the measured mass of the nucleus. We shall now make use of Albert Einstein's famous mass-energy equation is ;

$$\Delta E = (Z_{m_p} + N_{m_n} - M)c^2 \tag{3}$$

$$\Delta E = (\Delta m)c^2 \tag{4}$$

$$E_{binding} = (\Delta m)c^2 \tag{5}$$

The mass of a nucleus (collectively), therefore, is less than the mass of its constituents (individually) and, there is mass defects, which converted to energy according to Einstein's energy formula. The effects of these forces acting on the nucleons inside a nucleus are contained in the binding energy terms. This binding energy has a direct effect on the mass of an atom [3].

$$f = \frac{BE}{A} \tag{6}$$

2.2 Nuclear Binding Energy

Nuclear Binding energy (BE) is the energy required to separate a stable nucleus in to its constituent protons and neutrons; in essence, it is a qualitative measure of the nucleus stability. The binding energy per nucleon of the nucleus is the binding energy divided by the total number of nucleons. This implies that, measure of stability of the nucleus, larger the binding energy per nucleon, the greater the work that must be done to remove the nucleon from the nucleus. As well us the important features of the graph; excluding the lighter nuclei, the average binding energy per nucleon is about 8 MeV, the maximum binding energy per nucleon occurs at around mass number (A)=50, and corresponds to the most stable nuclei. For example,iron nucleus (Fe-56) is located close to the peak with a binding energy per nucleon value around 8.8 MeV. It is one of the most stable nuclides that exist.

The concept of nuclear binding energy is based on Einstein's famous equation energy is equal is to the products of mass defect and square of speed of light. According to which the energy and mass are inter-convertible [1].
Nucleus contains mainly protons and neutrons, and the sum of mass of this nucleon is almost equal to mass of the nucleus. More massive nuclei require extra neutrons to over come the coulomb repulsion of the protons in order to be stable.
Unfortunately, the experiments have shown that the sum of the masses of protons and neutrons individually always greater than the experimentally determined nuclear masses. The reason lies in the way the nature creates nucleus, it takes protons and neutrons together, puts them in a tiny space called nucleus. To take these nucleon and binds them together, some energy is needed, which the nature taken out of the masses of protons and neutrons.
This show that the nature is very smart, it does not spend any of its own energy, rather it converts some the masses of proton and neutron in to an energy and utilizes that the energy to bind the protons and neutrons within the nucleus. The masses difference of collective mass of the nucleus and masses of the individual separated nucleons is mass defect. By using the famous equation of Einstein binding energy is equal is to the products of mass defect and square of speed light, this mass defect converted to the binding energy [3].

Then nuclear binding energy: we have learned how to determine the mass defect, and we have learned how to convert this mass defect in to energy. This energy, called the binding energy (BE) of the nucleus is given by; the product of mass defect with square of speed light.

Where is the mass of the nucleus as determined by mass spectrometry. We also find that often the binding energy is expressed in terms of million electron volts (MeV). This conversion factor is; 1 amu = 931.5 MeV
Nuclear binding energy increases with the total number of nucleons atomic mass (A) and, therefore, it is common to quote the average binding energy per nucleon (f). The binding energy per nucleon is the share of binding energy of the nucleus of one nucleon with the nucleus [3].
The saturation phenomenon observed in nuclear radii also appears in nuclear binding energies. The binding energy B of a nucleus is defined as the negative of the difference between the nuclear mass and the sum of the masses of the constituents. Note that BE

is defined as a positive number:

$$BE(A,Z) = -BE(A,Z) \tag{7}$$

Where BE is the usual (negative) binding energy. The binding energy per nucleon as a function of A. We observe that B/A increases with atomic mass in light nuclei, and reaches a broad maximum around $A = 10 - 20$ in the light mass region. Beyond, it decreases slowly as a function of A (atomic mass). A convenient measure of the stability of a given nuclide is its binding energy BE.

The binding energy is the energy that would be needed to take the nucleus completely apart into its separated nucleons. The concept is similar to the atomic binding energy associated with electrons in atoms, but the magnitudes of nuclear binding energies are much greater. The binding energy of a nucleus atom can be calculated, using Einstein's mass-energy relation, from the rest atom of the nucleus and the rest masses of the constituent nucleons [3,9].

The result of this calculation is always positive because the total mass of the unbound nucleons is always greater than the mass of the nucleus. The extra mass comes from the energy which must be put into the system to pull it apart. Another way of looking at the relation is to say that if you could make Z protons and N neutrons combine to form a nucleus, then the total energy released would be B, given by equation. In practice binding energies are calculated using masses of atoms rather than nuclei, because that is what one usually measures directly. If you put the mass of an atom you are including the mass of Z electrons, so to compensate you use the mass of a hydrogen atom instead of the proton mass.

That gives an answer which is in error by the difference between the atomic binding energy of the Z electrons in atom and the atomic binding energy of Z hydrogen atoms, but since atomic binding energies are tiny compared with nuclear binding energies, the error is negligible.

The binding energy, BE, of a nucleus rises almost, but not quite, linearly with the atomic number (A). To emphasize the departure from linearity we can look at the average binding energy per nucleon, B/A.

The binding energy per nucleon changes with the mass of the nucleus. The biggest changes occur for the light nuclei [11].

2.3 Ground State Energy

Nucleons are fermions and the Pauli exclusion principle requested that neither two neutrons nor protons in the same state. The ground state of a nucleus with N neutrons and Z protons, the lowest N nucleons are occupied up to some energy, the neutron Fermi energy, and the lowest Z proton states occupied up to some energy, proton Fermi energy. The major success of shell model is the prediction of the angular momenta of nuclei in their ground state, i.e. nuclei with an even number of protons and even number of neutrons have angular momentum zero, and positive parity whereas, nuclei with an even number of proton and odd number of neutron. Therefore, the ground state energy of the system is ground energy per nucleon [4,8].

This is the proton or neutron separation energy, and hence, is of the order of binding energy per nucleon. The most stable nucleus of a given mass number A = N + Z with the neutron and proton Fermi energy approximately equal, at ground state a nuclei with an even number of neutrons and an even number of protons [9].

2.4 Nuclear Models

Atomic nuclei are complex and peculiar physical objects with interesting properties. The basic difficulties in the theory of nuclear structure are as: not good idea of interaction forces between the nucleons and the problem of mathematical solution of the quantum many body problems. Therefore, we need nuclear models in which some model physical system satisfactory to describes a definite set of nuclear properties, and at the same time allows a sufficiently simple mathematical treatment to be substituted for the nucleus [6]. Therefore the liquid drop model and nuclear shell models are the out standing representatives of each points respectively [9].

2.4.1 Liquid Drop Model

The liquid drop model of the nucleus was developed in 1937 by N. Bohr, Wheeler and Frenkel, 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 properties by the corresponding quantities, i.e.the radius, the density, the surface tension and the volume energy. In this model, the nucleus is considered as a spherical drop of an in compressible super dense nuclear fluid in which the nucleons move just like molecules in the liquid.

In this picture also we consider the nucleus as a drop of liquid. Comparing the nucleus with the drop, there factors which contribute to the total energy of the nucleus and the binding energy of the nucleus was calculated by the semi-empirical mass formula. Accord-

ing to this model the nuclear force is identical for every nucleon, and also it is saturate. And also the nucleus is very similar to a liquid drop and in the absence of external forces, it is spherical in shape. Major part of the forces present is due to the nuclear and coulomb interactions. This model suggests a semi-emperical mass formula for the binding energy of the nucleus. Liquid drop model was successful in giving an account of the systematic behavior of binding energy per nucleon as a function of mass number and it could justify the observed fission barrier. But it could not reproduce the observed.
This model is applicable to introduces energy is the sum of varies terms which are volume binding energy, coulomb energy, surface binding energy, pairing binding energy and a symmetry binding energy; in the semi-empirical mass formula for the nuclear masses i.e. The Bethe-Weizsacker nuclear mass formula, to explain the nuclear binding energies. It explains the alpha –decay energy and the nuclear stability of the beta-decay, but not account for the discontinuities of nuclear binding energy per nucleon with proton or neutron numbers have angular momentum zero, and positive parity [9,11].
Therefore The Bethe-Weizsacker nuclear mass formula; An excellent parametrization of the binding energies of nuclei in their ground state was proposed. This formula relies on the liquid drop analogy but also in corporate two quantum ingredients we mentioned in the previous section. 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 fermious are paired [14]. Those mass formula are;

a) Volume binding energy:

In the nucleus, the nucleons (neutron and proton) are held together by short range attractive forces which reduce the mass of nucleus lower than that of its constituents (neutron and proton).
All the nucleons are assumed inside the volume of the nucleus they all can make sufficient neighboring interaction.

$$\alpha_v = \alpha_v A \tag{8}$$

$$\alpha_v = 15.5 MeV. \tag{9}$$

b) Surface binding energy:

In nucleus there are some nucleons near the surface while some are nearer to the center. The nucleus on the surface are attracted by smaller number of nucleons in comparison to the inner nucleons. Hence, a force similar to the surface tension of a liquid acts on the nucleons near the free surface of the nuclear sphere. There are no forces acting from the outside. Therefore, the nucleus assumes a spherical shape. Hence,

$$\alpha_s = -\alpha_s A^{2/3} \tag{10}$$

$$\alpha_s = 17.8 MeV. \tag{11}$$

c) Coulomb binding energy:

The coulomb repulsion force between protons reduces the BE. The coulomb force does not exhibit the property of saturation. Thus the coulomb energy should be proportional to Z (Z-1) and inversely proportional to R. Therefore it is given by:

$$\alpha_c = -\alpha_c Z(Z-1)A^{-1/3} \tag{12}$$

$$\alpha_c = 0.691 MeV. \tag{13}$$

d) Asymmetry binding energy:

The nuclei with equal number of neutrons and protons exhibit the maximum stability. Thus, these nuclei have maximum binding energy. Any departure leads to less stability i.e, the reduction in BE. Thus, an asymmetry binding energy term is given by:

$$\alpha_{sy} = -\alpha_{sy}(A-2Z)^2 A^{-1} \tag{14}$$

$$\alpha_y = 23.75 MeV. \tag{15}$$

e) Pairing binding energy:

The proton and neutron have spin half and obey the Pauli exclusion principle. Therefor, the interaction between two different nucleons will be different from that between two identical nucleons. The nuclei with even number of proton and neutron are most abundant and most stable while nuclei with odd number of proton and neutron are least stable. The nuclei for which either proton or neutron is odd are intermediate in stability. The masses of even-even nuclei are high and masses of odd-odd nuclei are low. The pairing effect is denoted for even-even, even-odd or odd-even and odd-odd nuclei respectively.

$$\alpha_p = -\alpha_p \delta A^{-1/2} \tag{16}$$

$$\alpha_p = 33.22 MeV. \tag{17}$$

Totally, binding energy is the sum of various term which are volume binding energy, surface binding energy, coulomb binding energy, asymmetry binding energy and pairing binding energy [11].
Then the contribution to total energy are rest mass energy and the sum of various term are follows;

$$E_T = M_o(A_z)C^2 + \alpha_v A - \alpha_s A^{2/3} - \alpha_c Z(Z-1)A^{-1/3} - \alpha_{sy}(A-2Z)^2 A^{-1} - \alpha_p \delta A^{-1/2} \tag{18}$$

where
α_v =Volume Binding Energy
α_s =Surface Binding Energy
α_c =Coulomb Binding Energy
α_y =Asymmetry Binding energy
α_p =Pairing Binding Energy
$\delta = +1, for `A'$ even (Z-even and N-even)
$\delta = -1, for `A'$odd (Z-odd and N-odd)
$\delta = 0, for `A'$ odd (Z-even and N-odd or Z-odd and N-even)
in which
$\delta = 33.22 MeV$, $\alpha_v = 15.5 MeV$, $\alpha_s = 17.8 MeV$, $\alpha_c = 0.691 MeV$ and $\alpha_y = 23.75 MeV$
. And also binding energy is calculated by;

$$BE = E_T - M_o(A_z)C^2 \tag{19}$$

But binding energy per nucleon is given by;

$$f = BE/A \tag{20}$$

2.5 Isotopes

Isotopes are nuclei with the same number of protons, the same atomic number, but with a different number of neutrons, and different values of A (atomic mass number of nucleus). Isotopes are similar in their chemical properties because chemical changes involve only the electrons of the atoms and the number of electrons is the same as the number of protons. Or the atoms which make up a chemically pure substance of an element do not all have the same mass. For example, when analyze samples of many naturally occurring elements, we find they different atoms all having the same atomic number Z but different mass number A, i.e, different neutron numbers, Such atoms are called isotopes. All of the isotopes of one kind of atom have the same chemical properties. We have another expression, Isotopes are atoms with identical atomic numbers but different mass numbers. Most of the isotopes which occur naturally are stable, a few naturally occurring isotopes and all man made isotopes are unstable.

Isotopes are symbolized by writing the atomic mass number as a superscript before the atomic symbol.

For example; ^{10}C, ^{11}C, ^{12}C, ^{13}C, ^{14}C , ^{15}C and ^{15}C represent the carbon isotopes of atomic mass (A); 10, 11, 12, 13, 14, 15, and 16 respectively. And the atomic number Z is written as a subscript under the value of A. So the complete designation for these carbon nuclei would be; ^{12}C, and ^{13}C. The nuclei; ^{10}C, ^{11}C, ^{12}C, ^{13}C, ^{14}C, ^{15}C, and ^{16}C are all isotopes of carbon. But the element which have the nuclei of different elements which have the same number of A (atomic mass number of the nuclei) are called isobars. This means they must have different values of Z and N. Some isobars are,^{15}B, ^{15}C, ^{15}N, and ^{15}O. And also the nuclei of different elements with equal values of N are called isotones. Some isotones are; ^{13}B, ^{14}C, ^{15}N, and ^{16}O. The two basic nucleons have approximately the same mass, the neutron mass being 1.008665 atomic mass units (amu) and the proton mass being 1.007276 atomic mass units (amu) [3,4].

2.5.1 Stable Isotopes

It was observed quite early in the development of nuclear physics that, at least for light nuclei, the stable species contain approximately equal numbers of neutrons and protons. The light stable nuclei has led to the hypothesis that nuclear forces acts between neutrons and protons but not between neutrons and neutrons or between protons and protons.

Then the stability would be largest for the largest number of pairs of different types.
Stable nuclei are found with proton number Z=1 to Z=82. There are, however, a few minor exceptions, and we shall come back to see the significance. For each proton number,there are usually one or more stable which long-lived nuclei, or isotopes, each having a different number of neutrons. Since the chemistry of an element is determined by the electron outside the nucleus and, hence, the number of proton inside, the chemical properties of different isotopes are fairly similar to each other.
To a first -order approximately, stable nuclei have N=Z, with neutron number the proton number. The best example is perhaps the A=2 system. Here, we find that the only stable nucleus is the deuteron, made of one proton and one neutron. Di-proton and di-neutron are both known to be unstable. From this observation we can conclude that the force between a neutron and a proton is attractive on the whole but not necessarily that between a pair of neutrons or a pair protons [11].
We recall that there are two kinds of stability for a nuclear species; Those are Dynamical Stability and Beta Stability. Dynamical Stability is the breaking of the nuclear system into two or more parts is energetically impossible. And also Beta-stability; the transformation of a neutron in to a proton (or vice versa) with the emission (capture) of an electron and a neutrino is energetically impossible. Stable isotopes are used in the same way as radioactive isotopes in soil/plant studies.
Whereas radioactive isotopes emit particles which are captured in photo multiplier tubes and counted stable. Isotopes are separated from each other by passing a gas containing them through a strong magnetic field, which deflects them differential according to their mass.
The most common stable isotope used is necessary to supply energy but a large number of other stable isotopes are produced which are increasingly being used in agricultural studies. If the binding energy is greater than zero, and it is necessary to supply energy in order to break the nucleus in to its constituent parts.
We also find the binding energy per nucleon to be a useful value. This value is found by dividing the total binding energy by the number of nucleons. Increase in binding energy per nucleon as atomic mass increases. This increases is generate by increase force per nucleon in the nucleus, as each additional nucleons, attracted by other nearby nucleons, and thus more tightly bound. The region of increasing binding energy is followed by a region of relative stability (saturation).
Attractive nuclear forces in this region, as atomic mass increases, are nearly balanced by repellent electromagnetic forces between protons, as the atomic number increases. The binding energy per nucleon is rising as each nucleon surrounds it self with which it interact attractively. In this region protons and neutrons can be added equally easily since the

effect of the weak electrostatic repulsion is small [4].
By steeply rising part of the carve there are one or two striking in the relatively smooth carve. In the main isotopes of light mass region (nuclei) such as boron, carbon, nitrogen, oxygen, fluorine and neon, the most stable combination of neutrons and of protons are when the numbers are equal. Depending on this fact you can plot the graph of the binding energy per nucleon as a function of the number of nucleon or atomic number (A). A graph of the binding energy per nucleon as a function of the number of nucleon is plot.

2.5.2 Unstable Isotopes

A few naturally occurring isotopes and all of the man- made isotopes are unstable. If the binding energy is less than zero, the nucleus is unstable, and it will disintegrate spontaneously. The only unstable nuclei found naturally on earth are those with lifetimes comparable to or longer than the age of solar system(5 billion years) or as decay products of other long-lived species. Unstable isotopes can become stable by releasing different types of particles. And also nuclei that are unstable decay; many such decays are governed by another force is weak nuclear force.
unstable isotopes is that the isotopes has a measurable abundance and no decay has ever been observed (ultimately all nuclei heavier than the iron group are unstable,but it takes almost forever for them to decay).One must also include any lepton masses emitted or absorbed in a weak decay (less decay) or alpha-decay [14].

Odd-odd nucleon are unstable /less stable/ than even-even and even-odd/odd-even/ nuclei,but have life times greater than 1,000,000,000 years.i.e greater than the age of the earth.
Now, by using the formula of total energy per nucleon to calculate the nucleon ground state energy which is stable isotopes or unstable isotopes [10].

2.6 Nuclei Species

It's the collective term for proton and neutrons in side of a nucleus. This term allows nuclear scientists to distinguish between nuclei that differing any way; number of protons, neutrons, or energy configuration of either. A type of atom specified by its atomic number, atomic mass, and energy state, such as carbon-14. Its characterized by its atomic number and its mass number. An atomic species in which the atoms have the same atomic number and mass number. An individual atom in such species and also a particular isotopes of an element, identified by the number of protons and neutrons in the nucleus [11,13].

Depending the number of proton and the number of neutrons in the nucleus the following nuclei species discuss; For A = 4n, such types of nucleides (nuclei species) as lower values. A= 4n have even masses. There nuclei are the most stable, but less so. For A= 4n+2, such types of nuclides (nuclei species) as higher values. A= 4n+2 also have even masses and higher binding energy. Because of pairing effects. There nuclei are the most stable and have spin zero in their ground state. For A=odd such types of nuclei there exists one and only one stable isotopes. A odd atomic mass (A) have tends to lower binding energy, less stable, half integer spin and odd mass numbers are its some times is called fermions.

Also few beta stable nuclides, higher energy, part of a core in the nucleus and spin is zero. Include even Z-members. Have one stable isobar. There nuclei are the last stable. Therefore, ups and downs increase their differences as atomic mass increases. Finally, the total ground state energy per nucleon for nuclei with A=4n, A=4n+2 and odd A has been calculated by Semi-empirical Mass Formula [11].

Chapter 3

3 Materials and Method

In this chapter; source of data, the materials needed, the method used during this study and data analysis have been discussed in details as follows.

3.1 Materials

For this study, the materials used were published articles, books, journals, computer program code,internet access, lap top, flash disc and stationary materials were used.

3.2 Methodology

Research Methods; is a style of conducting a research work, which determines by the nature of the problem.

3.2.1 Method of Data Analyzing and Numerical

The data of nuclear ground state energy per nucleon as a function of atomic mass in the range between A=10 and A=20 were displayed in graphs and tables.

3.2.2 Computational Method

Nuclear ground state energy per nucleon depend up on the total energy of semi-empirical mass formula calculate the binding energy per nucleon in the range of atomic masses between 10 to 20. By using the equations; (18), (19) and (20), theoretically calculated data have been obtained.

3.2.3 Method of Data Presentation and Analysis

The data calculated during this work together with available data in literature have been displayed in tables and graphs. Based on the tables and graphs the validity of data by comparing with available data has been made. Also the behavior of the data in each tables and graphs has been discussed after each tables and graphs.

Chapter 4

4 Result and Discussion

In this work, nuclear ground state energy per nucleon as a function of A (atomic mass) in the range between ten (10) to twenty (20) region have been calculated.
In this chapter, the data obtained in this work has been presented the theoretical data with experimental data available in literature. In this range there are different types of elements there such as; Boron (B), Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F) and Neon (Ne). In which these elements are in the range of atomic mass (A) between ten (10) to twenty (20) region. Tables and graphs (figures) have been used to discuss ground state total energy, binding energy per nucleon and rest mass energy of the isotopes included in this range.

4.1 The Theoretical Binding Energy per Nucleon for the Isotopes in the Range A = 10 to 20, compared with Experiment value

As shown in Table 4.1, some of the isotopes binding energy per nucleon were displayed. The theoretical data were calculated during this work by different methods theoretical and experimental data from literature [11,14]. For the rest of the isotopes binding energy per nucleon not displayed in table 1: we are unable to find experimental data in literature. When the calculated data in this work is compared with the experimental data, it is in agreement with a relative percentage error less than 10 %.
There is an initial sharp rise with atomic mass (A) to a maximum of about 7.93 MeV per nucleon near amass of 16. In the light nucleus, where one in the nucleus of them interacts with all the other nucleons and, therefore, its binding energy increases with the mass number. However, the size of a nucleus increase with atomic mass (A) and when it exceeds that the range of inter nucleon force, the nucleon will interact only with its neighbors which lies with in the range. Consequently, the binding energy of a nucleon due to the nuclear force, the nucleon will tend to approach a constant value at large atomic mass (A). BE/A for some of the isotopes, compared with Experiment.

The data obtained for some of the isotopes together with experimental data has been displayed in Table 4.1 and Fig. 4.1.

Table 1: 4.1 Nuclear binding energy per nucleon for selected isotopes

Nucleus	A	Z	TheBE/Nucleon (MeV)	ExpBE/Nucleon (MeV)
B	10	5	5.99	6.47
B	11	5	6.73	6.92
C	12	6	7.67	7.68
C	13	6	7.11	7.46
N	14	7	7.33	7.47
N	15	7	7.39	7.69
O	16	8	7.93	7.97
O	17	8	7.36	7.46
F	19	9	7.73	7.77

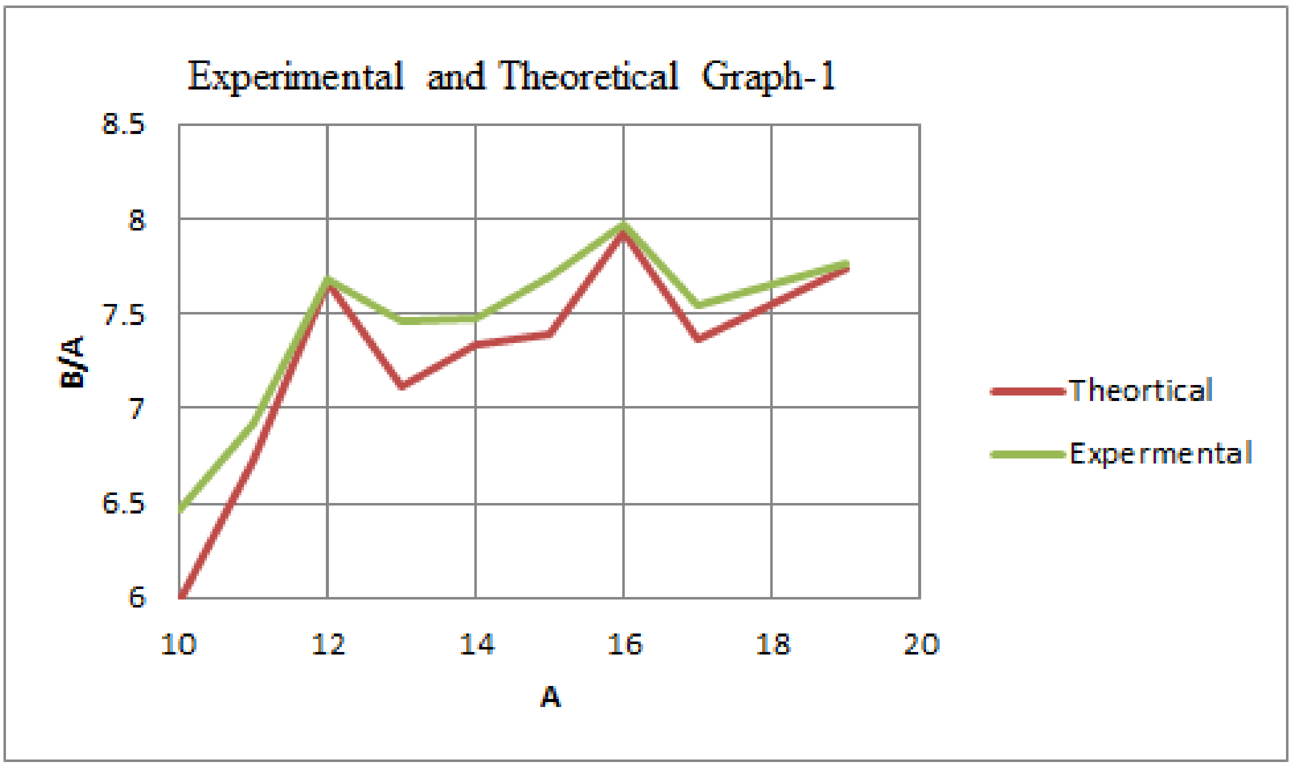

Figure 1: 4.1 Experimental and theoretical graph of B/A for the isotope

From Figure 4.1, both the calculated and experimental curves follow the same pattern, and deviates with in a range below a relative percentage error is b/n 0.13 and 7.34 as displayed in Tale 4.2. This shows that the calculation is acceptable.

The percentage error of the calculation for the isotopes shown in Table 4.1 were as summarized in Table 4.2

Table 2: 4.2 Summary of the percentage error for the ground state energy per nucleon calculation.

Isotope	Percentage error (%)
^{10}B	7.34
^{11}B	2.85
^{12}C	0.13
^{13}C	4.8
^{14}N	1.94
^{15}N	4.01
^{16}O	0.58
^{17}O	2.25
^{19}F	2.04

As can be seen from Table 4.2, the percentage error of the calculation (the calculation data compered with experiment) were less than 10%. Thus calculation is in the acceptable range. From Table 4.1 and Figure 4.1, we see that binding energy per nucleon depends on the nucleon number A and there are local peaks is similar positions of the graph with both calculated /theoretical/ and experimental data. From these peaks we see that, the binding energy is not smooth function of nucleon number A. Nuclei with very low or very high mass numbers have lesser binding energy per nucleon and are less stable because the lesser the binding energy per nucleon, the easier it is to separate the nucleus in to its constituent nucleons. An isotopes which having large number of binding energy per nucleon much more stable than the other isotopes. For example, ^{11}B, ^{12}C, ^{15}N, ^{16}O, and ^{19}F.

4.2 Calculated Binding Energy per Nucleon (B/A) for Isotopes in the Range Between A=10 to 20

4.2.1 Binding Energy as a Function of Atomic Mass (A) for Boron Isotopes

Table 3: 4.3 Binding energy per nucleon for the isotopes of boron

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
B	5	5	10	10.01293	6.000
B	5	6	11	11.00930	6.730
B	5	7	12	12.01435	5.761
B	5	8	13	13.01778	6.211
B	5	9	14	14.02540	5.132
B	5	10	15	15.03108	5.270
B	5	11	16	16.03984	5.265
B	5	12	17	17.04693	4.234

The calculated data of binding energy per nucleon for 8 isotopes of boron were calculated. As can be seen from the data is as shown in Table 4.3.

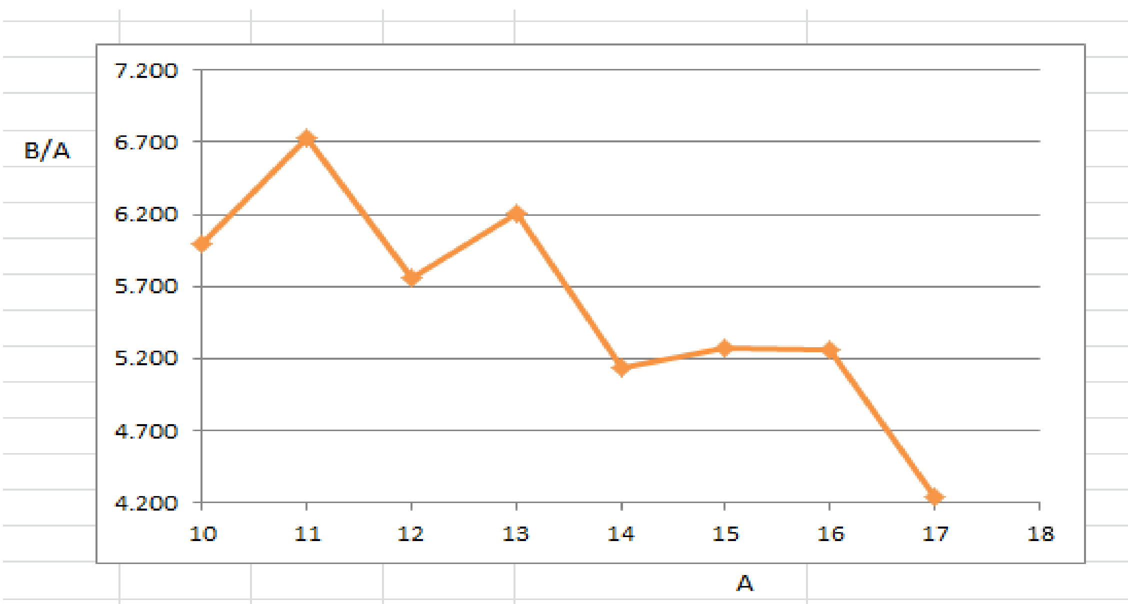

Figure 2: 4.2 Figure of binding energy per nucleon versus nucleon number for the boron isotopes

From Table 4.3 we can see that binding energy is maximum for the isotopes ^{11}B. And also ^{13}B and ^{15}B have local maximum points. The calculated data of binding energy per nucleon for 8 isotopes of boron were calculated. As can be seen from the data is as shown in Table 4.3. The local minimum points are seen for the isotopes ^{14}B, ^{10}B, ^{12}B and ^{16}B

have local minimum points.
Binding Energy as a Function of Atomic Mass for Boron Isotopes.

The data obtained for some the boron isotopes calculated data has been displayed in Table 4.3 and Fig. 4.2. This shows that the binding energy per nucleon has local maximum at isotopes with (even-odd) nucleon numbers.

An isotopes containing odd-odd pair of nucleons has locally smaller value of binding energy per nucleon (B/A) compared to its neighboring odd-even isotopes with one less neutron.

According to the graph above or graph 4.2 this shows to their stability as follows. For example, ^{11}B, ^{13}B, ^{15}B and ^{17}B, more stable than there ^{10}B, ^{12}B, ^{14}B and ^{16}B. The reason is because according to their stability , odd-even nuclei more stable than odd-odd nuclei according to the above graph and the value of table of boron isotopes. An isotopes which having large number of binding energy per nucleon much more stable than the other isotopes. For example, ^{11}B.

Maximum binding energy on the top point of the graph, because of short range of attraction and minimum binding energy on the low point of the graph, because of long of attraction. Nuclei with very low or very high mass numbers have lesser binding energy per nucleon and are less stable because the lesser the binding energy per nucleon, the easier it is to separate the nucleus in to its constituent nucleons.

4.2.2 Binding Energy as a Function of Atomic Mass (A) for Carbon Isotopes

Binding energy as a function of atomic mass for carbon isotopes are follows.The data obtained for some the carbon isotopes calculated data has been displayed in Table 4.4 and Fig. 4.3.

Table 4: 4.4 Binding energy per nucleon for the isotopes of carbon

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
C	6	4	10	10.01685	6.376
C	6	5	11	11.01143	5.864
C	6	6	12	12.00000	7.670
C	6	7	13	13.00335	7.110
C	6	8	14	14.00324	7.650
C	6	9	15	15.01059	6.771
C	6	10	16	16.014701	6.727
C	6	11	17	17.02257	6.049
C	6	12	18	18.02675	6.065

In the Table 4.4, the calculated /theoretical/ data during this work has been displayed

for 9 isotopes of carbon. From there we see that binding energy is maximum for the isotopes; ^{10}C, ^{12}C, ^{14}C and ^{16}C have local maximum points. At the same time we see that the binding energy is minimum for the isotopes ^{11}C, ^{13}C, ^{15}C and ^{17}C, they have local minimum points.
This shown that binding energy per nucleon has local maximum at isotopes with (even-even) nucleon numbers.

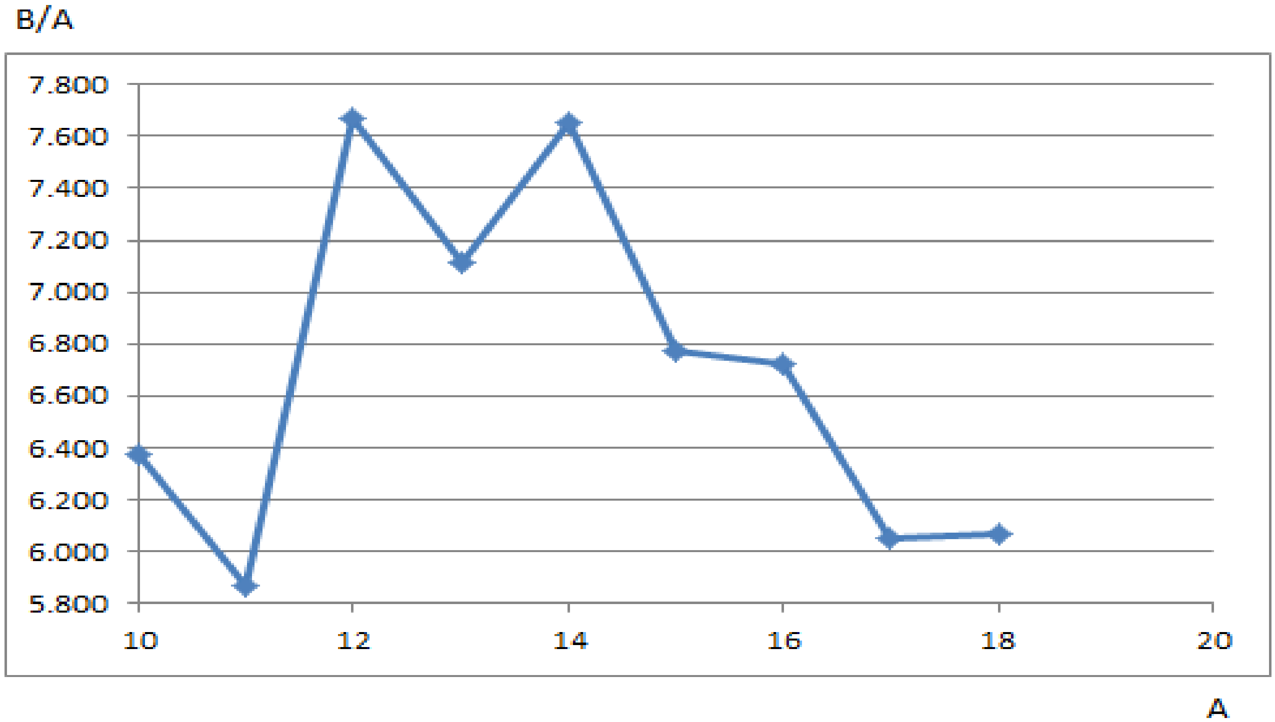

Figure 3: 4.3 Figure of binding energy per nucleon versus nucleon number for the carbon isotopes

An isotopes containing even-odd pair of nucleons has locally smaller value of binding energy per nucleon (B/A) compared to its neighboring even-even isotopes with one less neutron.
For example, ^{10}C , ^{12}C, ^{14}C , ^{16}C and ^{18}C , much more stable than ^{11}C , ^{13}C , ^{15}C and ^{17}C.
The reason is according to their stability even-even nuclei is much more stable than odd-even nuclei or even-odd nuclei. Nuclei with very low or very high mass numbers have lesser binding energy per nucleon and are less stable because the lesser the binding energy per nucleon, the easier it is to separate the nucleus in to its constituent nucleons.
For example, ^{11}C and ^{17}C. And an isotopes which having large number of binding energy per nucleon much more stable than the other isotopes, for instance, ^{12}C. Nuclei with even number of neutron or even number of proton much more tightly bound.

Maximum binding energy on the top point of the graph, because of high force and short range of attraction and minimum binding energy on the low point of the graph , because of low force and long range of attraction.

4.2.3 Binding Energy as a Function of Atomic Mass (A) for Nitrogen Isotopes

Binding energy as a function of atomic mass for nitrogen isotopes are follows.The data obtained for some the Nitrogen isotopes calculated data has been displayed in Table 4.5 and Fig. 4.4.

Table 5: 4.5 Binding energy per nucleon for the isotopes of nitrogen

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
N	7	3	10	10.04165	1.040
N	7	4	11	11.02609	4.543
N	7	5	12	12.0186132	5.778
N	7	6	13	13.00574	6.844
N	7	7	14	14.00307	7.330
N	7	8	15	15.00010	7.391
N	7	19	16	16.00610	6.822
N	7	10	17	17.00844	7.174
N	7	11	18	18.01409	6.485

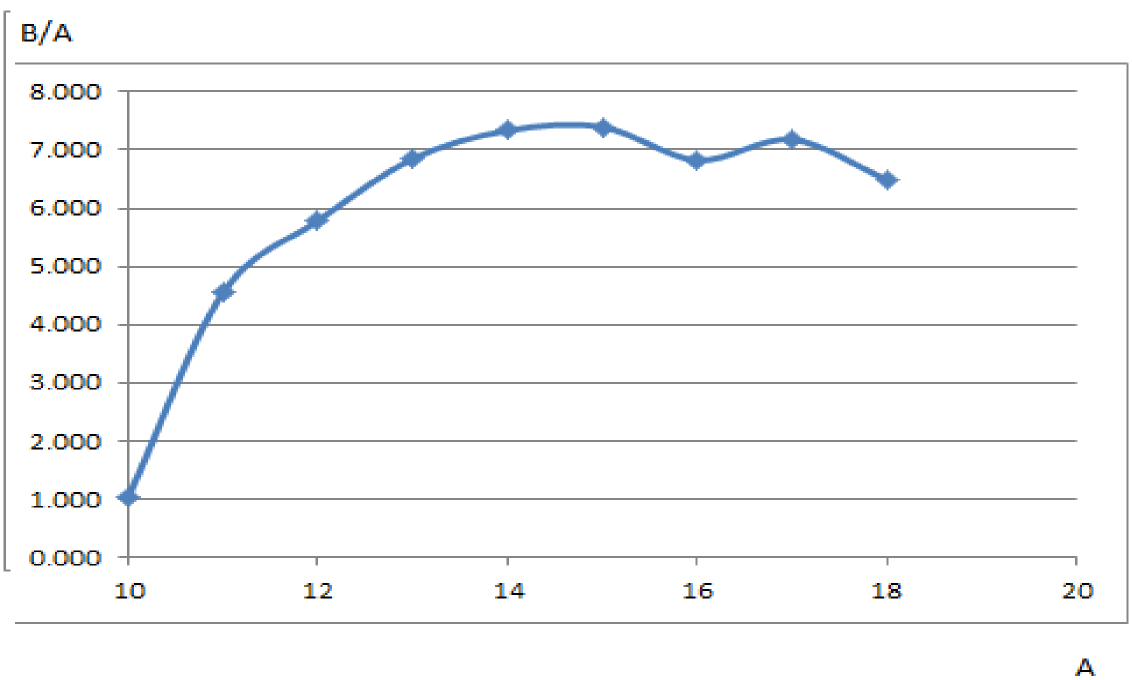

Figure 4: 4.4 Figure of binding energy per nucleon versus nucleon number for the nitrogen isotopes

In the Table 4.5, calculated /theoretical/ data in the present work has been displayed for 9 isotopes of nitrogen.
From these we can see that binding energy is maximum for the isotopes; ^{11}N, ^{13}N, ^{15}N and ^{17}N have local maximum points. Again from these we see that binding energy is minimum for the isotopes ^{10}N. And also ^{12}N, ^{14}N, ^{16}N and ^{18}N have local minimum points.
This shows that the binding energy per nucleon has local maximum at isotopes with (odd-even) nucleon numbers.
An isotopes containing odd-odd pair of nucleons has locally minimum value of binding energy per nucleon (B/A) compared to its neighboring even-odd isotopes with one less neutron. Depending up on the graph and table above or table 4.5 and graph 4.4 their stability is determine. For example , ^{11}N, ^{15}N and ^{17}N , more stable than those ^{10}N, ^{12}N, ^{14}N and ^{16}N.
The reason is according to their stability odd-even nuclei more stable than odd-odd nuclei according to graph 4.4 and table 4.5 values of nitrogen isotopes. Nuclei with very low or very high mass numbers have lesser binding energy per nucleon and are less stable because the lesser the binding energy per nucleon, the easier it is to separate the nucleus in to its constituent nucleons. For example, For example, ^{10}N and ^{18}N.
Among those isotopes which having large value of binding energy per nucleon and much more stable than the other, for example, ^{15}N. Nuclei with even number of neutron or odd number of proton more tightly bound.

Maximum binding energy on the top point of the graph , because of short range of attraction and minimum binding energy on the low point of the graph , because of long range of attractive

4.2.4 Binding Energy as a Function of Atomic Mass (A) for Oxygen Isotopes

BE as a function of atomic mass for Oxygen isotopes are follows. The data obtained for some the Oxygen isotopes calculated data has been displayed in Table 4.6 and Fig. 4.5

Table 6: 4.6 Binding energy per nucleon for the isotopes of oxygen

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
O	8	4	12	12.03426	4.477
O	8	5	13	13.02482	5.399
O	8	6	14	14.00859	7.117
O	8	7	15	15.00306	7.131
O	8	8	16	15.99491	7.930
O	8	9	17	16.99913	7.361
O	8	10	18	17.99915	8.030
O	8	11	19	19.00358	7.251
O	8	12	20	20.00408	7.651

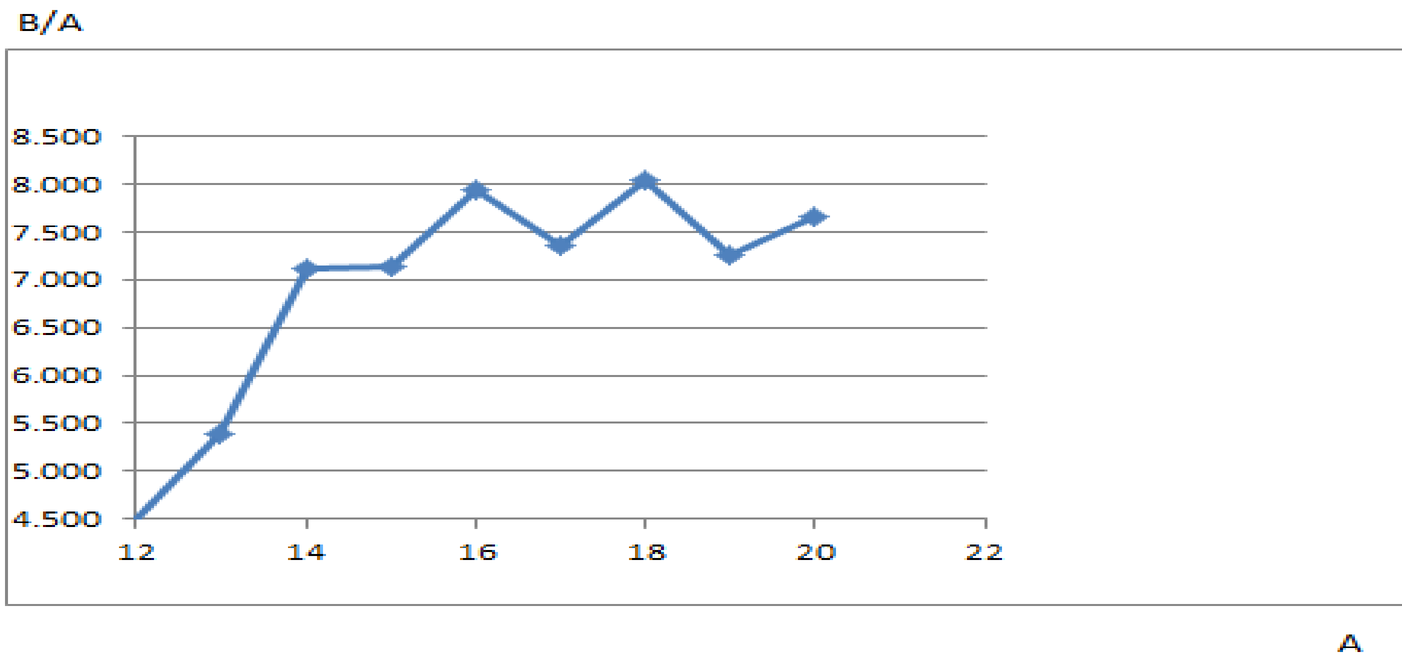

Figure 5: 4.5 Figure of binding energy per nucleon versus nucleon number for the oxygen isotopes

In Table 4.6, the calculated /theoretical/ data during this work has been displayed for 9 isotopes of oxygen.

From there we see that the binding energy is maximum for the isotopes; ^{12}O, ^{14}O, ^{16}O, ^{18}O and ^{20}O have local maximum points. Again from there we see that binding energy is minimum for the isotopes ^{13}O, ^{15}O, ^{17}O and ^{19}O have local minimum points.
This shows that binding energy per nucleon has local maximum at isotopes with (even-even) nucleon numbers.
An isotopes containing even-even pair of nucleons has locally smaller value of binding energy per nucleon (B/A) compared to its neighboring even-odd isotopes with one less neutron. Depending up on the Figure 4.5 and Table 4.6 determine their stability. For example, ^{12}O, ^{14}O, ^{16}O, ^{18}O and ^{20}O , much more stable than ^{13}O, ^{15}O, ^{17}O and ^{19}O. This is because according to their stability even-even nuclei according to the above Figure 4.5 and Table 4.6 value of oxygen isotopes.
Nuclei with very low or very high mass numbers have lesser binding energy per nucleon and are less stable because the lesser the binding energy per nucleon, the easier it is to separate the nucleus in to its constituent nucleons.
For example, ^{12}O and ^{19}O. An isotopes which having large number of binding energy per nucleon much more stable than the other isotopes, for example, ^{19}O. Nuclei with even number of neutron or even number of proton much more tightly bound.
Maximum binding energy on the top point of the graph , because of short range of attraction and Minimum binding energy on the low point of the graph , because of long range of attraction.

4.2.5 Binding Energy as a Function of Atomic Mass (A) for Flourine Isotopes

Table 7: 4.7 Binding energy per nucleon for the isotopes of flourine

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
F	9	5	14	14.03432	4.067
F	9	6	15	15.01778	5.988
F	9	7	16	16.01146	6.312
F	9	8	17	17.00209	7.357
F	9	9	18	18.00093	7.211
F	9	10	19	18.99840	7.730
F	9	11	20	19.99998	7.411

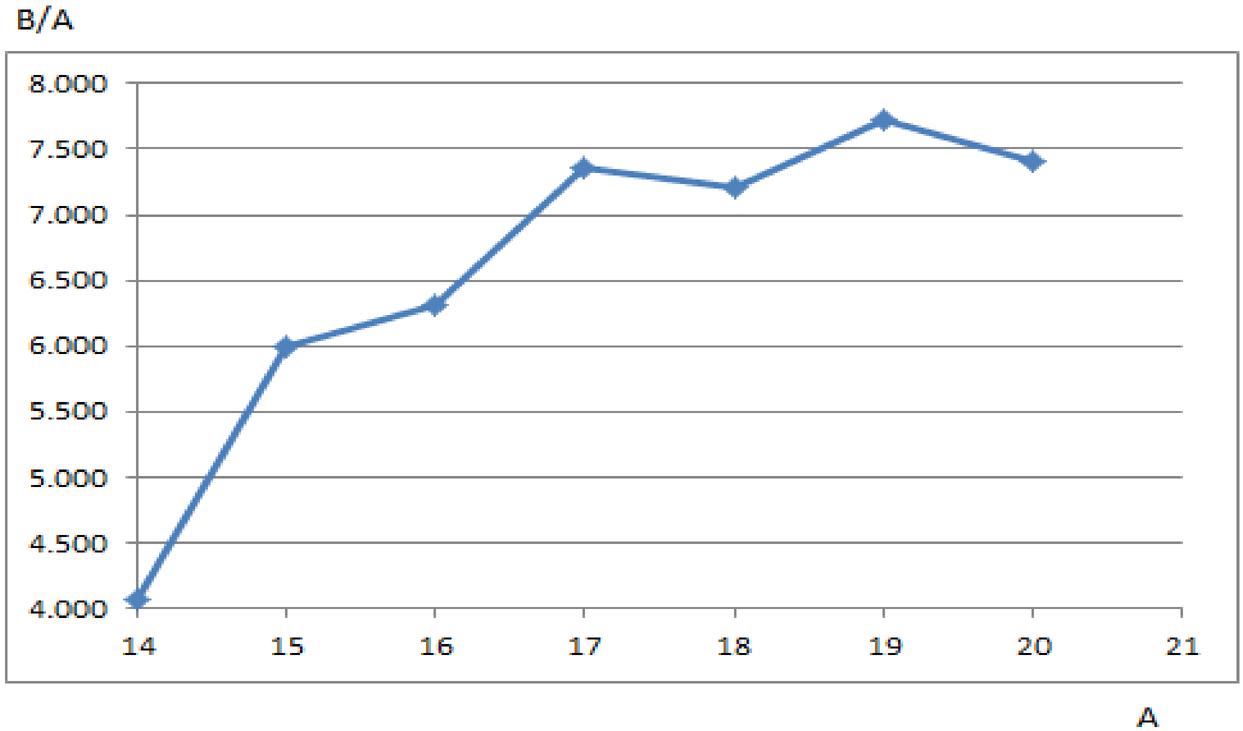

Figure 6: 4.6 Figure of binding energy per nucleon versus nucleon number for the flourine isotopes

In the Table 4.7, calculated /theoretical/ data during this work has been displayed for 7 isotopes of Flourine. From these we can see that the binding energy is maximum for the isotopes; ^{15}F, ^{17}F and ^{19}F have local maximum points. And also from there we see that binding energy is minimum for the isotopes; ^{14}F, ^{16}F and ^{18}F have local minimum points. This shown that binding energy per nucleon has local maximum at isotopes with (even-odd) nucleon numbers.

An isotopes containing odd-odd pair of nucleons has locally smaller value of binding energy per nucleon (B/A) compared to its neighboring odd-even isotopes with one less neutron. The graph and table of flourine or table 4.7 and graph 4.6 determine their stability. For example, ^{15}F, ^{17}F and ^{19}F, more stable than those ^{14}F, ^{16}F, ^{18}F and ^{20}F.

The reason is because according to their stability odd-even nuclei more stable than odd-odd nuclei according to the above graph 4.6 and table 4.7 value of Flourine isotopes. An isotopes which having large number of binding energy per nucleon much more stable than the other isotopes. For example, ^{19}F. Because Odd-even nuclei more stable than that of nuclei which have odd-odd nuclei isotopes. Nuclei with even number of neutron or odd number of proton more tightly bound.

Maximum binding energy on the top point of the graph , because of short range of attraction and minimum binding energy on the low point of the graph , because of long range of attraction is made.

4.2.6 Binding Energy as a Function of Atomic Mass (A) for Neon Isotopes

Table 8: 4.8 Binding energy per nucleon for the isotopes of neon

Nucleus	Z	N	A	Mass of Nucleon (amu)	The BE/Nucleon (MeV/nuc)
Ne	10	5	15	15.04317	3.9624
Ne	10	6	16	16.02575	5.9282
Ne	10	7	17	17.01771	6.4150
Ne	10	8	18	18.00571	7.5301
Ne	10	9	19	19.00188	7.5801
Ne	10	10	20	19.99244	7.6212

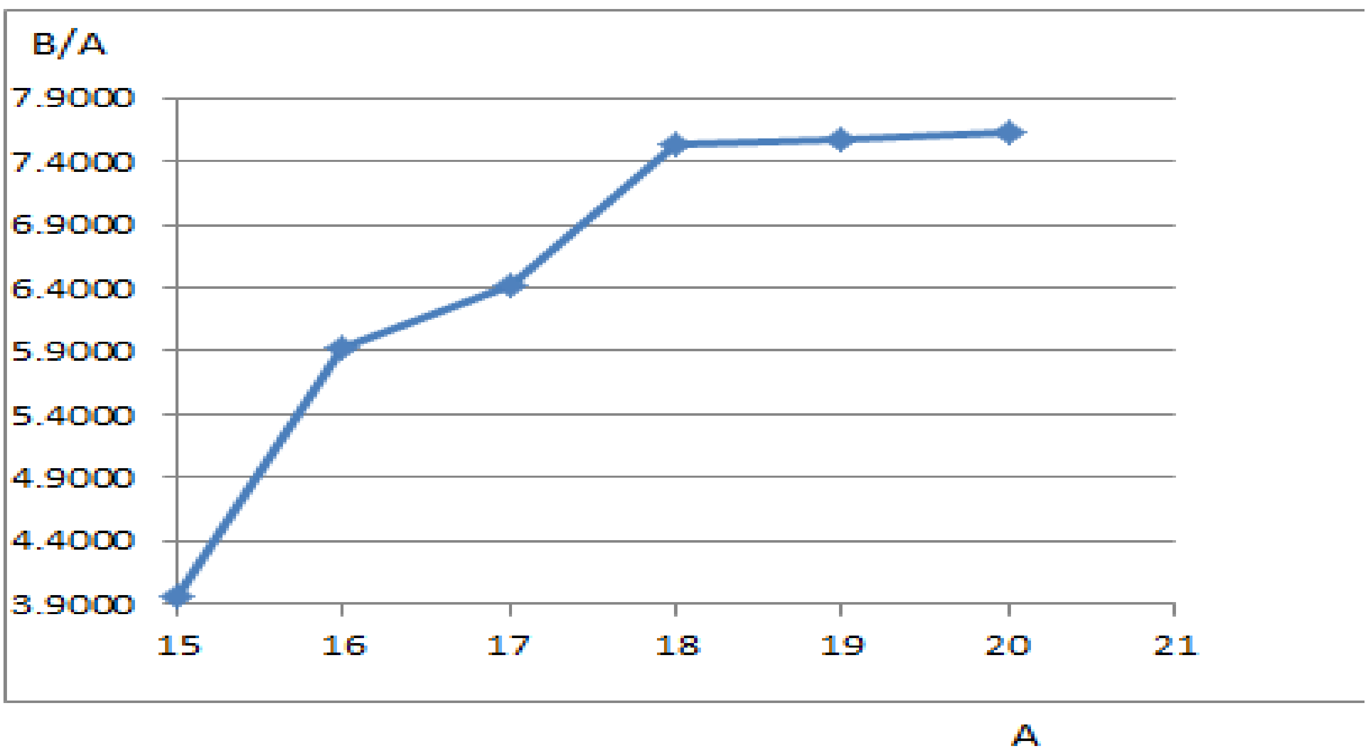

Figure 7: 4.7 Figure of binding energy per nucleon versus nucleon number for the neon isotopes

In the table 4.8, calculated /theoretical/ data during this work has been displayed for 7 isotopes of neon. From there we see that binding energy is maximum for the isotopes; ^{16}Ne, ^{18}Ne and ^{20}Ne have local maximum points.
Again from there we see that binding energy is minimum for the isotopes; ^{15}Ne, ^{17}Ne and ^{19}Ne have local minimum points.
This shown that binding energy per nucleon has local maximum at isotopes with (odd-even) nucleon numbers.
An isotopes containing odd-odd pair of nucleons has locally smaller value of binding energy per nucleon (B/A) compared to its neighboring odd-even isotopes with one less neutron. Depending up on the graph and table above or table 4.8 and graph 4.7 display their stability. For example , ^{16}Ne, ^{18}Ne and ^{20}Ne , much more stable than , ^{15}Ne, ^{17}Ne and ^{19}Ne.
Why, because according to their stability , even-even nuclei much more stable than even-odd of nuclei according to the above graph 4.7 and table 4.8 value of neon isotopes. An isotopes which having large number of binding energy per nucleon much more stable than the other isotopes. For example, ^{20}Ne. Why because even-even nuclei much more stable than that nuclei of which have even-odd nuclei isotopes.

4.3 Binding Energy per Nucleon of Isotones with: A = 15, A = 16 and A = 17

4.3.1 Binding Energy per Nucleon of Isotones with: A = 15

Table 9: 4.9 Binding energy per nucleon of Isotones with:A=15

Nuclous	Z	The BE/Nucleon (MeV/nuc)
B	5	5.27
C	6	6.77
N	7	7.39
O	8	7.13
F	9	5.98
Ne	10	3.96

From Fig.4.8 proton number increase, because of coulomb's repulsion tends to decrease binding energy. When we see the behavior of the B/A as a function of proton number shown in Fig. 4.8 binding energy per nucleon. When the proton number increase, we were expecting B/A to decrease. But in Fig. 4.8 between Z=5, Z=6 and Z=7, binding energy per nucleon increased. This is because of asymmetric term. The symmetric term in the binding energy depends on proton and neutron number difference. When number

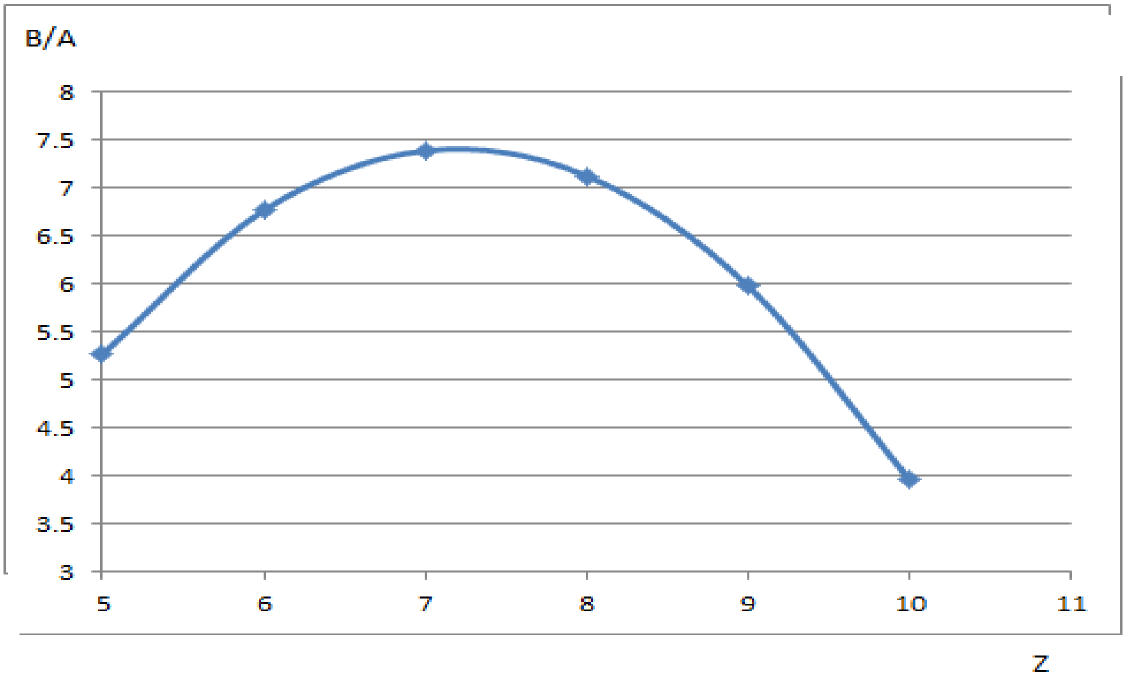

Figure 8: 4.8 Figure of binding energy per nucleon versus proton number for isotones with:A=15

of proton is equal to number of neutron, the asymmetric term becomes zero at points in the Fig. 4.8 (Z=7, and Z=8) the asymmetric term assumes its value equal in absolute value. But B/A at the points is not equal because one more proton repulsion effect.

4.3.2 Binding Energy per Nucleon of Isotones with: A=16

Table 10: 4.10 Binding energy per nucleon of Isotones with:A=16

Nuclous	Z	The BE/Nucleon (MeV/nuc)
B	5	5.26
C	6	6.72
N	7	6.82
O	8	7.93
F	9	6.31
Ne	10	5.92

From Fig. 4.9 proton number increase, because of coulomb's repulsion tends to decrease binding energy. When we see the behavior of the B/A as a function of proton number shown in Fig. 4.9 binding energy per nucleon. When the proton number increase, we were expecting B/A to decrease. But in Fig. 4.9 between Z=5, Z=6 and Z=7, binding energy per nucleon increased. This is because of asymmetric term. The symmetric term in the binding energy depends on proton and neutron number difference. When number

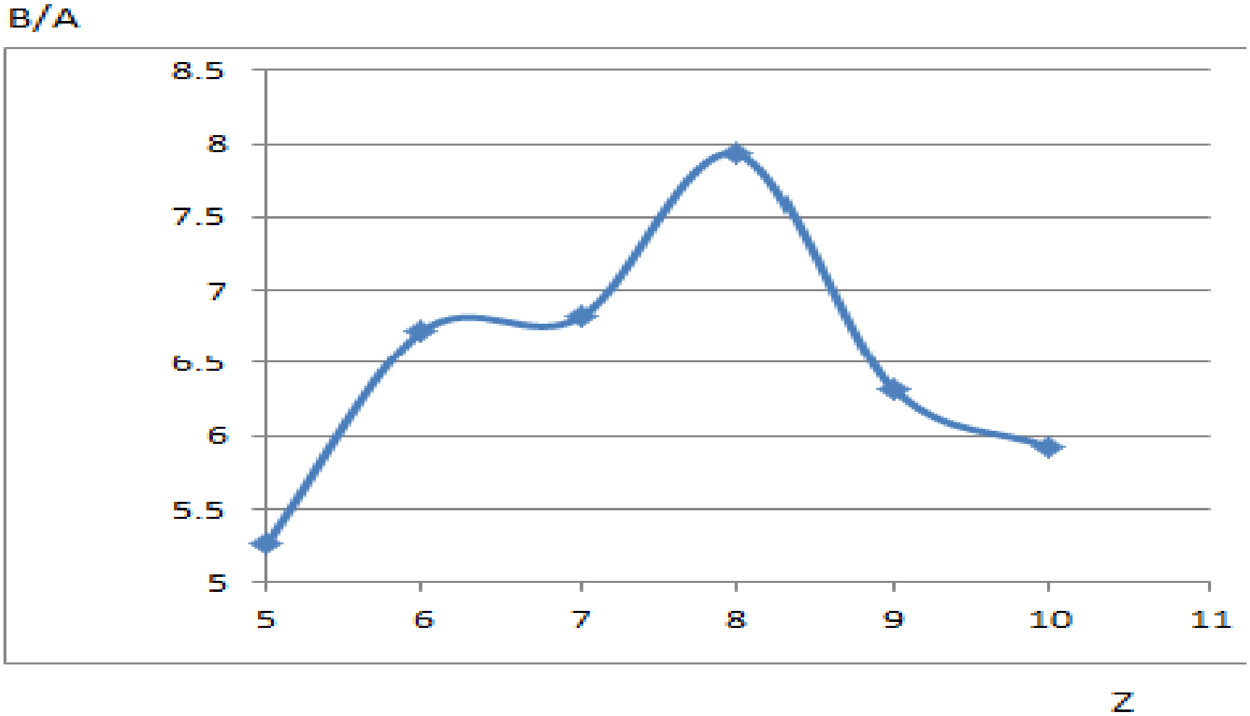

Figure 9: 4.9 Figure of binding energy per nucleon versus proton number for isotones with:A=16

of proton is equal to number of neutron, the asymmetric term becomes zero at points in the Fig. 4.9 (Z=7, and Z=8) the asymmetric term assumes its value equal in absolute value. But B/A at the points is not equal because one more proton repulsion effect.

4.3.3 Binding Energy per Nucleon of Isotones with: A = 17

Table 11: 4.11 Binding energy per nucleon of Isotones with:A=17

Nuclous	Z	The BE/Nucleon (MeV/nuc)
B	5	4.23
C	6	6.05
N	7	7.17
O	8	7.36
F	9	7.35
Ne	10	6.40

From Fig. 4.10 proton number increase, because of coulomb's repulsion tends to decrease binding energy. When we see the behavior of the B/A as a function of proton number shown in Fig. 4.10 binding energy per nucleon. When the proton number increase, we were expecting B/A to decrease. But in Fig. 4.10 between Z=5, Z=6, Z=7

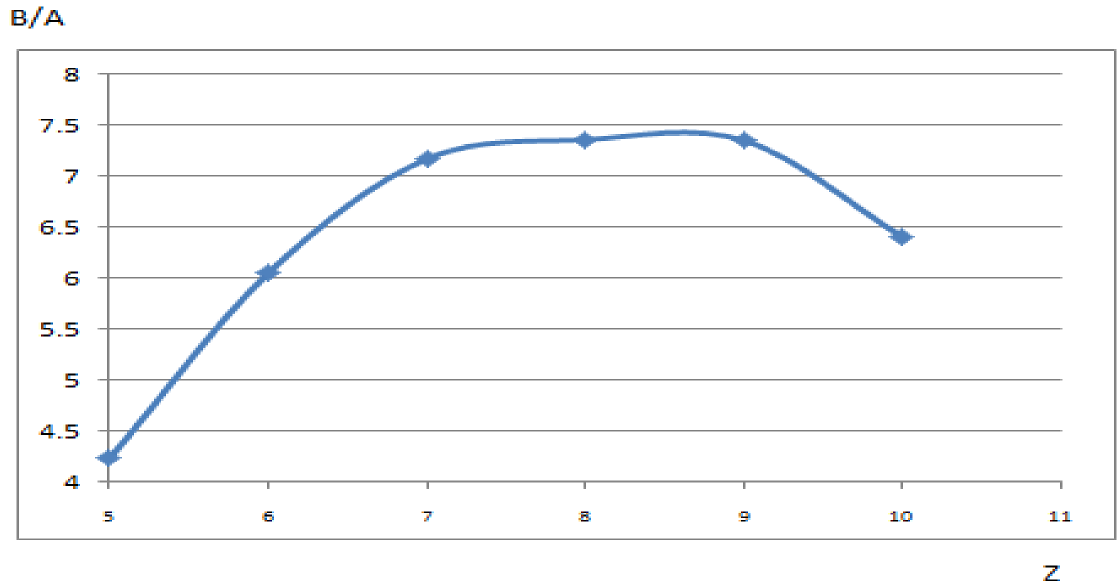

Figure 10: 4.10 Figure of binding energy per nucleon versus proton number for isotones with:A=17

and Z=8 binding energy per nucleon increased. This is because of asymmetric term. The symmetric term in the binding energy depends on proton and neutron number difference. When number of proton is equal to number of neutron, the asymmetric term becomes zero at points in the Fig. 4.10 (Z=9, and Z=10) the asymmetric term assumes its value equal in absolute value. But B/A at the points is not equal because one more proton repulsion effect.

Chapter 5

5 Conclusion

With in the nuclear ground state energy per nucleon as a function of atomic mass (A) in the range between A=10 and A=20 region have been displayed. The results thus obtained were compered with the corresponding experimental data with calculated data, it is found that, much well over a nearest range or almost the same values. Figure 1, shows different local peaks is similar positions of the graph with both calculated and experimental data. From these peaks we see that, the binding energy is not smooth function of nucleon number A. In Table 4.2, binding energy is maximum for the isotopes ^{11}B and minimum for the isotopes ^{14}B. This shown that binding energy per nucleon has local maximum at isotopes with (even-odd) nucleon numbers than odd-odd nucleon numbers. In Table 4.3, binding energy is maximum for the isotopes ^{12}C and minimum for the isotopes ^{11}C. This shown that binding energy per nucleon has local maximum at isotopes with (even-even) nucleon numbers than even-odd nucleon numbers. In Table 4.4, binding energy is maximum for the isotopes ^{15}N and binding energy is minimum for the isotopes ^{10}N. This shown that binding energy per nucleon has local maximum at isotopes with (odd-even) nucleon numbers than odd-odd nucleon numbers. In Table 4.5, binding energy is maximum for the isotopes ^{18}O and binding energy is minimum for the isotopes ^{13}O. This shown that binding energy per nucleon has local maximum at isotopes with (even-even) nucleon numbers than even-odd nucleon numbers. In Table 4.6, binding energy is maximum for the isotopes ^{19}F and binding energy is minimum for the isotopes ^{14}F. This shown that binding energy per nucleon has local maximum at isotopes with (odd-even) nucleon numbers than (odd-odd) nucleon numbers. In Table 4.7, binding energy is maximum for the isotopes ^{20}Ne and binding energy is minimum for the isotopes ^{15}Ne. This shown that binding energy per nucleon has local maximum at isotopes with (even-even) nucleon numbers than (even-odd) nucleon numbers. Thus we can conclude from this work that; Isotopes with even-even pair of nucleons show greater binding energy per nucleon (i.e. highly bound) so that more stable. Compered to even- odd, and odd-odd isotopes. Isotopes having even-odd and/or odd-even pair of nucleons have better stability compered to these isotopes with odd-odd nucleons, due to relatively higher binding energy per nucleon. The binding energy per nucleon depends on the number of protons, as can be seen from Fig.4.8 - Fig.4.10.
i) When the proton number increases between isotones, and the effect of increasing the proton number is to decrease symmetric effect,then B/A increases. ii) When the proton number increase between isotones, increasing the symmetric effect, B/A decreases.

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