Chapter One

Introduction

1.1 Alpha Particles

Alpha particles consist of two protons and two neutrons, alpha particles contain 2 protons and 2 neutrons, and the interconnectedness between them causes difference in the mass and turns into a nuclear bond

1.2 Research problem:

Hydrogen atom is very important to study its components such as alpha particles.

This research focuses of calculating the mass defect and binding energy of alpha particles

1.3 Objective:

The mean goal of this research was to calculate the mass defect and binding energy of the alpha particles.

1.4 Thesis Layout:

In chapter one introduction, chapter two basic concepts, chapter three calculations, finally chapter four conclusions and recommendations

Chapter Two

Alpha Particles

2.1 Introduction:

Alpha particles consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α. The symbol for the alpha particle is α or α^{2+}.

Because they are identical to helium nuclei, they are also sometimes written as He^{2+}or 4 ${}^{4}_{2}He^{2+}$ indicating a helium ion with a +2 charge (missing its two electrons). If the ion gains electrons from its environment, the alpha particle can be written as a normal (electrically neutral) helium atom ${}^{4}_{2}He$.

Some science authors may use doubly ionized helium nuclei (He2+) and alpha particles as interchangeable terms. The nomenclature is not well defined, and thus not all high velocity

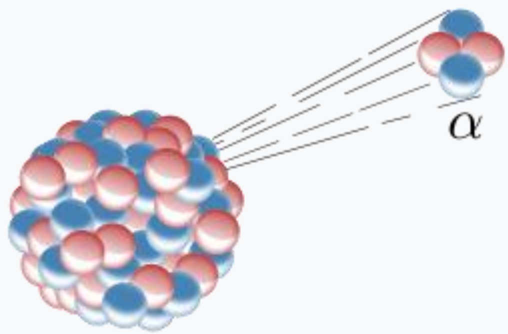
helium nuclei are considered by all authors to be alpha particles. As with beta and gamma rays/particles, the name used for the particle carries some mild connotations about its production process and energy, but these are not rigorously applied Thus, alpha particles may be loosely used as a term when referring to stellar helium nuclei reactions (for example the alpha processes), and even when they occur as components of cosmic rays [1].

A higher energy version of alphas than produced in alpha decay is a common product of an uncommon nuclear fission result called ternary fission. However, helium nuclei produced by particle accelerators (cyclotrons, synchrotrons, and the like) are less likely to be referred to as “alpha particles”. Alpha particles, like helium nuclei, have a net spin of zero. Due to the mechanism of their production in standard alpha radioactive decay, alpha particles generally have a kinetic energy of about 5 MeV, and a velocity in the vicinity of 5% the speed of light [1].

They are a highly ionizing form of particle radiation, an (when resulting from radioactive alpha decay) have low penetration depth. They are able to be stopped by a few centimeters of air, or by the skin. However, so-called long range alpha particles from ternary fission are three times as energetic, and penetrate three times as far. As noted, the helium nuclei that form 10–12% of cosmic rays are also usually of much higher energy than those produced by nuclear decay processes, and are thus capable of being highly penetrating and able to traverse the human body and also many meters of dense solid shielding, depending on their energy. To a lesser extent, this is also true of very high-energy helium nuclei produced by particle accelerators.

When alpha particle emitting isotopes are ingested, they are far more dangerous than their half-life or decay rate would suggest, due to the high relative biological effectiveness of alpha radiation to cause biological damage. Alpha radiation is an average of about 20 times more dangerous, and in experiments with inhaled alpha emitter up to 1000 times more dangerous, than an equivalent activity of beta emitting or gamma emitting radioisotopes [2].

The fundamental interactions responsible for alpha decay are a balance between the electromagnetic force and nuclear force. Alpha decay results from the Coulomb repulsion[3] between the alpha particle and the rest of the nucleus, which both have a positive electric charge, but which is kept in check by the nuclear force. In classical physics, alpha particles do not have enough energy to escape the potential well from the strong force inside the nucleus (this well involves escaping the strong force to go up one side of the well, which is followed by the electromagnetic force causing a repulsive push-off down the other side) [3].



Alpha decay	
Composition	2 protons, 2 neutrons
Statistics	Bosonic
Symbol	α, α^{2+}, He^{2+}
Mass	$6.644657230(82)\times10^{-27}$ kg[1] 4.001506179127(63) u 3.727379378(23) GeV/c^2
Electric charge	2 e
Spin	0[2]

Fig (2.1): Alpha (α) decay

Alpha (α) decay occurs when the neutron to proton ratio is too low. Alpha decay emits an alpha particle, which consists of two protons and two neutrons. This is the same as a helium nucleus and often uses the same chemical symbol $^4He_2$. Alpha particles are highly ionizing (e.g. deposits energy over a short distance). Since alpha particles lose energy over a short distance, they cannot travel far in most media. For example, the range of a 5 MeV alpha particle in air is only 3.5 cm. Consequently, alpha particles will not normally penetrate the outermost layer of the skin. Therefore, alpha particles pose little external radiation field hazard.

Shielding of alpha particles is easily accomplished with minimal amounts of shielding [3].

Examples of alpha particle emitting radio-nuclides include ^{238}U, ^{239}Pu, and ^{241}Am

$$^{238}_{91}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He.$$

$$^{239}_{94}Pu \rightarrow ^{235}_{92}U + ^{4}_{2}He.$$

$$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ^{4}_{2}He.$$

After the emission of an α particle, the daughter product remaining, will be reduced by 4 in its mass number, and 2 in its atomic number, as could be verified in the examples above [3].

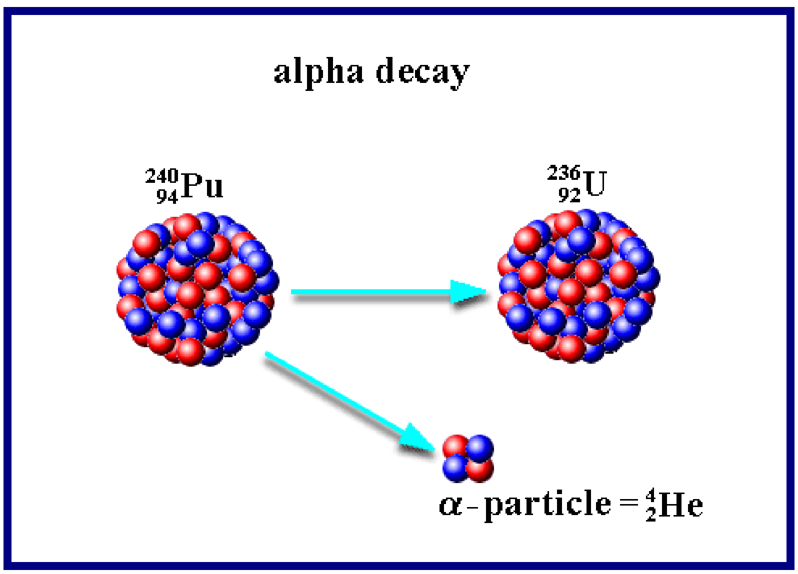


Fig (2.2): Alpha particles

2.2 Alpha particles – mass and charge

A positively charged particle that consists of two protons and two neutrons bound together. It is emitted by an atomic nucleus undergoing radioactive decay and is identical to the nucleus of a helium atom. Because of their relatively large mass, alpha particles are the slowest and least penetrating forms of nuclear radiation. They can be stopped by a piece of paper.

The process by which a radioactive element emits an alpha particle is called alpha decay [3].

Alpha decay results in the atomic number of the atom being decreasedby two and the mass number being decreased by four.

An alpha particle is made up of 2 protons and 2 neutrons, which have no charge, hence its charge is equal to that of 2 protons. The mass of the particle its approximately the sum of the masses of the neutrons and of the protons:

$6.6446572 \times 10^{-27}$kg

Proton:

Mass: 1.67×10^{-27}kg

Charge: 1.6×10^{-19} Coulomb.

Alpha Particle:

Mass: 4 times the mass of proton

$= 6.68 \times 10^{-27}$kg

Charge: 2 times the charge of proton,

$= 3.2 \times 10^{-19}$ Coulomb.

2.3 Einstein: mass–energy equivalence

In physics, mass–energy equivalence states that any-thing having mass has an equivalent amount of energy and vice versa, with these fundamental quantities directly relating to one another by Albert Einstein's famous formula : $E = mc^2$

This formula states that the equivalent energy (E) can be calculated as the mass (m) multiplied by the speed of light (c = about 3×108 m/s) squared. Similarly, anything having energy exhibits a corresponding mass m given by its energy E divided by the by the squared of light speed. Because the speed of light is a very large number in everyday units, the formula implies that even an everyday object at rest with a modest amount of mass has a very large amount of energy intrinsically.

Chemical, nuclear, and other energy transformations may cause a system to lose some of its energy content (and thus some corresponding mass), releasing it as light (radiant) or thermal energy for example.

Mass–energy equivalence arose originally from special relativity as a paradox described by Henri Poincaré [4].

Einstein proposed it in 1905, in the paper Does the inertia of a body depend upon its energy-content?, one of his Annus Mirabilis (Miraculous Year) papers [5]. Einstein was the first to propose that the equivalence of mass and energy is a general principle and a consequence of the symmetries of space and time [5].

A consequence of the mass–energy equivalence is that if a body is stationary, it still has some internal or intrinsic energy, called its rest energy, corresponding to its rest mass.

When the body is in motion, its total energy is greater than its rest energy, ad, equivalently, its total mass (also called relativistic mass in this context) is greater than its rest mass. This rest mass is also called the intrinsic or invariant mass because it remains the same regardless of this motion, even for the extreme speeds or gravity considered in special and general relativity.

The mass-energy formula also serves to convert units of mass to units of energy (and vice versa), no matter what system of measurement units is used.

Einstein correctly described the equivalence of mass and energy as "the most important upshot of the special theory of relativity" (Einstein, 1919), for it is more than a mere curiosity of physics. According to Einstein's famous equation E = mc^2, the energy (E) of a body is numerically equal to the product of its mass (m) and the speed of light (c) squared. It is customary to refer to this result as "the equivalence of mass and energy," or simply "mass-energy equivalence," because one can choose units in which c = 1, and hence E = m. An important consequence of $E = mc^2$ is that a change in the rest-energy of a body is accompanied by a corresponding change to its inertial mass.

Einstein's equation, $E = m\,c^2$, where E is the energy equivalent of a mass, m, and c is the velocity of light. This difference is known as the mass defect and is a measure of the total binding energy (and, hence, the stability) of the nucleus. This binding energy is released during the formation of a nucleus from its constituent nucleons [5].

Chapter Three

Mass Defect

3.1 Introduction:

the amount by which the mass of an atomic nucleus differs from the sum of the masses of its constituent particles, being the mass equivalent of the energy released in the formation of the nucleus.

The observed atomic mass is slightly less than the sum of the masses of the protons, neutrons, and electrons that make up the atom. The difference, called the mass defect, is accounted for during the combination of these particles by conversion into binding energy, according to an equation in which the energy (E) released equals the product of the mass (m) consumed and the square...

Mass defect (also referred to as mass deficit) is a phenomenon which occurs in physics. When we calculate the theoretical mass of a nucleus using the masses of protons and neutrons and compare it to the experimental mass, we observe that there is a small, but relevant, difference in the two masses. This is a result from the binding energy which is responsible for binding protons and neutrons together in the nucleus of an atom. Simply put, some of the mass from the protons and neutrons in the nucleus is converted to the binding energy (according to Einstein's $E = mc^2$) [6].

Mass and energy can be seen as two names (and two measurement units) for the same underlying, conserved physical quantity.

Thus, the laws of conservation of energy and conservation of (total) mass are equivalent and both hold true.

proved inadequate in the face of the special theory of relativity.

It was therefore merged with the energy conservation principle—just as, about 60 years before, the principle of the conservation of mechanical energy had been combined with the principle of the conservation of heat [thermal energy] [7].

If the conservation of mass law is interpreted as conservation of rest mass, it does not hold true in special relativity.

The rest energy (equivalently, rest mass) of a particle can be converted, not "to energy" (it already is energy (mass)), but rather to other forms of energy (mass) that require motion, such as kinetic energy, thermal energy,

or radiant energy. Similarly, kinetic or radiant energy can be converted to other kinds of particles that have rest energy (rest mass).

In the transformation process, neither the total amount of mass nor the total amount of energy changes, since both properties are connected via a simple constantThis view requires that if either energy or (total) mass disappears from a system, it is always found that both have simply moved to another place, where they are both measurable as an increase of both energy and mass that corresponds to the loss in the first system. Physics", Science, Washington, DC, vol. 91, no. 2369, [8,9].

3.2 equation of mass defect

The difference between the unbound system calculated mass and experimentally measured mass of nucleus (mass change) is denoted as Δm. It can be calculated as follows:

Mass change = (unbound system calculated mass) − (measured mass of system) i.e., (sum of masses of protons and neutrons) − (measured mass of nucleus) Mass change (decrease) in bound systems, particularly atomic nuclei, has also been termed mass defect, mass deficit, or mass packing fraction. [9].

3.3 Mass defect of alpha particle equation

The latter scenario is the case with nuclei such as helium: to break them up into protons and neutrons, one must inject energy. On the other hand, if a process existed going in the opposite direction, by which hydrogen atoms could be combined to form helium, then energy would be released. The energy can be computed using $E = \Delta m\, c^2$ for each nucleus, where Δm is the difference between the mass of the helium nucleus and the mass of four protons (plus two electrons, absorbed to create the neutrons of helium).

Alpha decay is usually restricted to the heavier elements in the periodic table. (Only a handful of nuclides with atomic numbers less than 83 emit an α-particle.) The product of α-decay is easy to predict if we assume that both mass and charge are conserved in nuclear reactions. Alpha decay of the ^{238}U "parent" nuclide, for example, produces ^{234}Th as the "daughter" nuclide [9].

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} \qquad (\alpha - \mathrm{decay}) \tag{3.1}$$

3.4 calculation of mass defect of alpha particle

The sum of the mass numbers of the products (234 + 4) is equal to the mass number of the parent nuclide (238), and the sum of the charges on the products (90 + 2) is equal to the charge on the parent nuclide.

Building an alpha particle For the ^{4}He nucleus

the atomic mass unit (1 u) is defined as 1/12
of the mass of a 12C atom

Total mass of 2 protons = 2 * 1.00728 = 2.01456 amu

Total mass of 2 neutrons = 2* 1.00866 = 2.01732 amu

Total mass of nucleons = 4.03188 amu

Mass of Alpha particle (measured) = 4.00153 amu

Mass defect Δm = 0.03035 amu

These are the results you would get (all masses in unified atomic mass units (u).) There is a difference of 0.03035 u between them, the helium nucleus is lighter than the four particles that made it [9].

Chapter Four

Binding energy

4.1 Introduction:

In the energy that connects the components of nucleus with each other.

4.2 Binding energy

is the energy required to disassemble a whole system into separate parts. A bound system typically has a lower potential energy than the sum of its constituent parts; this is what keeps the system together. Often this means that energy is released upon the creation of a bound state. This definition corresponds to a *positive* binding energy.

In general, binding energy represents the mechanical work that must be done against the forces which hold an object together, disassembling the object into component parts separated by sufficient distance that further separation

requires negligible additional work.

In bound systems, if the binding energy is removed from the system, it must be subtracted from the mass of the unbound system, simply because this energy has mass [9].

Thus, if energy is removed (or emitted) from the system at the time it is bound, the loss of energy from the system will also result in the loss of the mass of the energy from the system.[9] System mass is not conserved in this process because the system is “open” (i.e., is not an isolated system to mass or energy input or loss) during the binding process.

There are several types of binding energy, each operating over a different distance and energy scale. The smaller the scale of a bound system, the higher its associated binding energy [9].

In astrophysics, the gravitational binding energy of an object, such as a celestial body, is the energy required to expand the material to infinity. Solely for the purpose of comparison with the other types of binding energy, if a body with the mass and radius of the Earth were made purely of hydrogen-1, then the gravitational binding energy of that body would be about 0.391658 eV per atom.

If a hydrogen-1 body had the mass and radius of the Sun, its gravitational binding energy would be about 1,195.586 eV per atom.

At the molecular level, bond energy and bond dissociation energy are measures of the binding energy between the atoms in a chemical bond. It is the energy required to disassemble a molecule into its constituent atoms. This energy appears as chemical energy, such as that released in chemical explosions, the burning of chemical fuel and biological processes. Bond energies and bond-dissociation energies are typically in the range of few eV per bond. For example, the bond-dissociation energy of a carbon-carbon bond is about 3.6 eV.

At the atomic level, the atomic binding energy of the atom derives from electromagnetic interaction, mediated by photons. It is the energy required to disassemble an atom into free electrons and a nucleus [10].

Electron binding energy is a measure of the energy required to free electrons from their atomic orbits. This is more commonly known as ionization energy. Among the chemical elements, the range of ionization energies is from 3.8939 eV for the first electron in an atom of cesium to 11.567617 keV for the 29th electron in an atom of copper.

At the nuclear level, nuclear binding energy is the energy required to disassemble a nucleus into the free, unbound neutrons and protons it is composed of. It is the energy equivalent of the mass defect, the difference between the mass number of a nucleus and its true measured mass. Nuclear binding energy derives from the nuclear force or residual strong force, which is mediated by three types of mesons. The average nuclear binding energy per nucleon ranges from 2.22452 MeV for hydrogen-2 to 8.7945 MeV for nickel-62.

At a yet more fundamental level, quantum chromo dynamics binding energy is the energy which binds the various quarks together inside a hadron. This energy derives from the strong interaction, which is mediated by gluons. The chromo dynamic binding energy inside a nucleon, for example, amounts to approximately 99% of the nucleon's mass. The chromo dynamic binding energy of a proton is about 928.9 MeV, while that of a neutron is about 927.7MeV [10].

4.3 Binding Energy Formula

Energy equivalent to mass defect is called binding energy. A nucleus is like a rigid spherical ball formed by bringing together a large number of tiny spherical balls in the form of nucleons.

Something is needed to keep the nucleons together. That something is binding energy which serves the purpose of glue. To provide the binding energy each nucleon has to contribute some of its mass resulting in mass defect. **"Binding energy is a measure of the strength of the bondage. More binding energy means more strong binding."**

Binding Energy Formula is expressed as

$$\bar{B} = \frac{B}{A} = \frac{(\Delta m)c^2}{A} \tag{3.1}$$

Binding energy is the energy equivalent of the mass deficiency, energy released in the formation of an atom from subatomic particles.

$$\text{Binding Energy} = \text{mass defect} \times c^2$$

$$\text{binding Energy per nucleon} = \frac{\text{Total binding energy}}{\text{Number of nucleons}}$$

Larger the mass defect, greater the binding energy and more stable is the nucleus.

Calculation can be employed to determine the nuclear binding energy of nuclei. The calculation involves determining the mass defect, converting it into energy, and expressing the result as energy per mole of atoms, or as energy per nucleon[11].

A nuclear decay happens to the nucleus, meaning that properties ascribed to the nucleus change in the event.

In the field of physics the concept of "mass deficit" as a measure for "binding energy" means "mass deficit of the neutral atom" (not just the nucleus) and is a measure for stability of the whole atom.

As nuclei grow bigger still, this disruptive effect becomes steadily more significant. By the time polonium is reached (84 protons), nuclei can no longer accommodate their large positive charge, but emit their excess protons quite rapidly in the process of alpha radioactivity—the emission of helium nuclei, each containing two protons and two neutrons. (Helium nuclei are an especially stable

combination.) Because of this process, nuclei with more than 94 protons are not found naturally on Earth (see periodic table). The isotopes beyond uranium (atomic number 92) with the longest half-lives are plutonium-244 (80 million years) and curium-247 (16 million years) [12].

4.4 The Structure and Binding Energy of the Alpha Particle the Helium 4 Nucleus

Helium-4is a non-radioactive isotope of the element helium. It is by far the most abundant of the two naturally occurring isotopes of helium, making up about 99.9% of the helium on Earth. Its nucleus is identical to an alpha particle, and consists of two protons and two neutrons.

One of the major problems of the physics of nuclei is the explanation of the high binding energy of Helium 4 nucleus, the alpha particle. A deuteron (proton-neutron pair) has a binding energy of 2.225 million electron volts (Mev) but an alpha particle has a binding energy of 28.3 Mev. (The higher the binding energy of a particle the more energy is required to break it up into its constituent parts.)

If an alpha particle is considered to be the combination of two deuterons then there is a gain in energy of 23.85 Mev from putting them together. From one perspective the creation of an alpha particle is the same as the creation of a deuteron but with double weight constituent particles. For the analysis here the difference between the masses of the proton and the neutron will be ignored; i.e., the mass of the neutron will be taken to be the same as the mass of the proton.

4.5 The Binding Energy Curve

Different nuclei have different binding energies. These are determined by the combination of protons and neutrons in the nucleus [12].

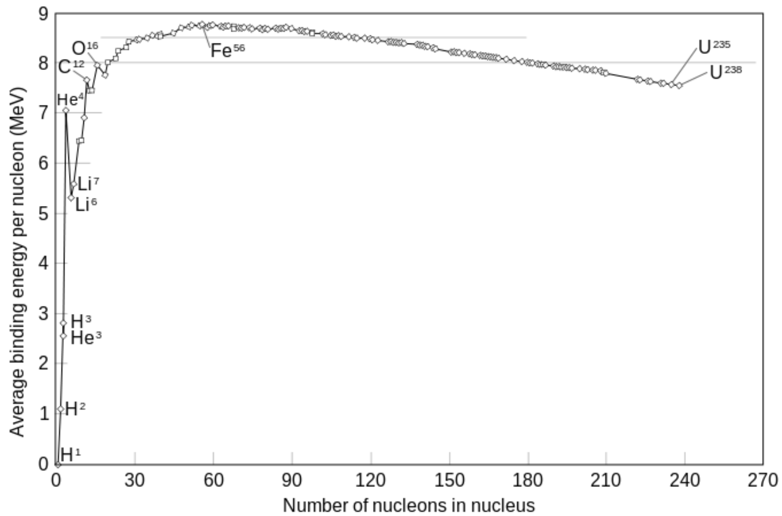


Fig (4.1): Number of nucleons in nucleus

Binding energy per nucleon of common isotopes. The binding energy per particle of helium-4 is significantly larger than all nearby nuclides.

The unusual stability of the helium-4 nucleus is also important cosmologically[13]. See fig (4.1)

4.6 Calculation of the binding energy of alpha particles

Nuclear binding energy can be computed from the difference in mass of a nucleus, and the sum of the masses of the number of free neutrons and protons that make up the nucleus. Once this mass difference, called the mass defect or mass deficiency, is known, Einstein's mass-energy equivalence formula $E = mc^2$ can be used to compute the binding energy of any nucleus.

For the ^4He nucleus, the binding energy computed as below:

Total mass of 2 protons = $2 \times 1.00728 = 2.01456$ amu

Total mass of 2 neutrons = $2 \times 1.00866 = 2.01732$ amu

Total mass of nucleons = 4.03188 amu

Mass of Alpha particle (measured) = 4.00153 amu

Mass defect Δm = 0.03035 amu

Hence, Binding energy of ^4He = 28.3 MeV.

(i.e. 0.03035 amu $\times$ 931.5 MeV/amu) [13].

4.7 The Binding Energies of Integral Alpha Particle Nuclides

The binding energy of the He4 nucleus, the alpha particle, is relatively high compared to that of close by nuclides. It is 28.3 million electron volts (MeV) compared with 2.2 MeV for the H2, deuteron, 7.7 MeV for the He3 and 8.5 MeV for the H3, tritium, nuclides. On the other hand for nuclides which include the components of the alpha particle plus additional nucleons the binding energies at the 28 MeV level. This suggest that when the components of an alpha particle are present, two protons and two neutrons, such a particle is formed.

When the binding energies of nuclides which could contain an integral number of alpha particles are reviewed, as in the table below, one finds that there is generally an excess in binding energy above that which could be attributed to the formation of alpha particles [14].

Table 4.1: the binding Energies of Nuclei which could contain an integral Number of Alpha particles [14]

Element	Neutrons	Protons	Binding Energy	Number of Alpha Particles	Binding Energy	Difference
He	2	2	28.295674	1	28.295674	0
Be	4	4	56.49951	2	56.591348	0.091838
C	6	6	92.161728	3	84.887022	7.274706
O	8	8	127.619336	4	113.182696	14.43664
Ne	10	10	160.644859	5	141.47837	19.166489

The graph of the excess binding energy shown as the last column in the above table displays some interesting characteristics. See fig (4.2)

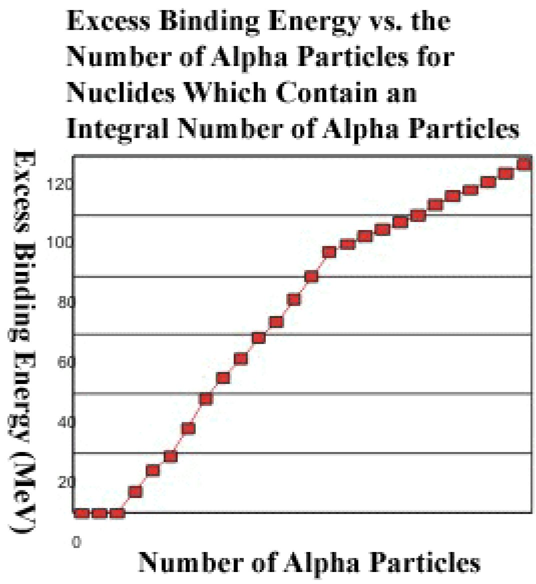


Fig (4.2): Number of alpha particles

There is no significant excess binding energy for two alpha particles but for three there is. The additional binding energy for the number of alpha particles above two is roughly constant at about 7 MeV per additional alpha particle until a level of 14 alpha particles is reached. There after the increase is about 3 MeV per additional alpha particle, as shown below [14]. See fig (4.3)

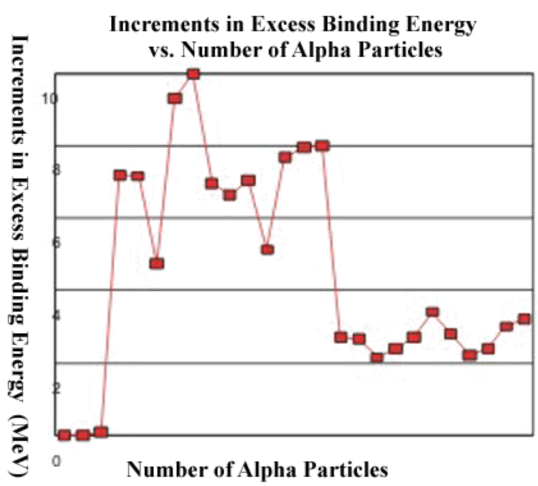


Fig (4.3):

Chapter Five

Conclusion and Recommendation

5.1 Conclusion:

The mass defect of Alpha particles was found to be 03035 amu and the binding energy of alpha particles was found to be 3– 28 Mev.

5.2 Recommendations:

The researches in this field may calculated the equivalent energy, momentum, velocity, kinetic energy of alpha particles.

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