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Nuclear physics lectures

Physics Department - Fourth Stage

Preparation By

Dr. Ali Kalaf Aobaid

College of Education for Pure Sciences / University of Anbar

Refrence: Principles of Nuclear Physics by Mayerhof, translated by Assem Azzouz

chapter one

Basic Concepts of Nuclear physics

The study of nuclear physics focuses on two main problems:

1- Try to understand how the kernel is built.

2- Attempting to understand the law that governs the forces that bind the nucleus.

Basic Nuclear properties

Nuclear traits are divided into two categories in terms of their time dependence:

1- Nuclear properties that do not depend on time: they are the fixed properties that do not change with time, such as mass, volume, charge and intrinsic angular momentum, which is called nuclear spin.

2- Nuclear properties that depend on time: they are unstable properties that change with time, such as radioactive decay and industrial conversion of elements (nuclear reactions). These irritable cases are a characteristic of the second type.

Nuclear Mass

The chemist William Prout assumed in 1815 that the mass of any atom (M) is given by:

$$M = \text{integer} * MH$$

where (MH) is the mass of a hydrogen atom. This relationship was used for the purpose of comparing atomic masses, and the whole number (the integer) is what is now called the mass number and is denoted by the symbol (A), and therefore the above equation can be written in the following formula:

$$M = A\ MH$$

So he called the Prout hypothesis the integer hypothesis, and this relationship means that the nucleus of an atom contains only positively charged particles, and since the hydrogen atom is the simplest atom in nature, it was assumed that the mass of any atom is made up of a group of hydrogen atoms. For example, the oxygen atom consists of 16 Hydrogen and Lithium-7 are made up of 7 hydrogen atoms.

However, Barclay noticed by X-ray scattering that the atomic number (Z), which represents the number of electrons in the atom, as well as the number of positive nuclear charges (protons) is not equal to the mass number (A), and this result has led to

The emergence of the first hypothesis about the nuclear structure, which states that ((the nuclei are composed of (A) of protons and (A-Z) of electrons bound inside the nucleus)). Since the mass of electrons is relatively small, it does not affect the previous equation and remains in effect. This hypothesis is called the Prout hypothesis or the electron-proton hypothesis. The emission of alpha and beta rays (of a particle nature) from some radioactive atoms has led to the belief that atoms are made of parts Elementary or basic, while it was believed that atoms are the smallest parts of matter that participate in chemical reactions.

This hypothesis has succeeded in explaining the emission of β-negative beta particles, considering each of them a nuclear electron. and two nuclear electrons, but it failed to explain the following results:

1- Energy and momentum of negative beta particles: If the β^{-} particles emitted from some nuclei were originally present inside those nuclei in the form of nuclear electrons, as the hypothesis states, their energy should be about 60 MeV according to what Heisenberg as we will see later, while practically we find that its energy does not exceed 4MeV, which indicates that its emission is instantaneous at the point of its creation or formation, as it results from the transformation of $p \leftarrow n$ according to the reaction: $n \rightarrow p + \beta^{-} + \bar{V}$

In terms of linear momentum, if β^{-} is already inside the nucleus as a nuclear electron, then the rebound of the nucleus must be opposite to the emission of β^{-}, while in practice this does not happen.

2- Conservation of angular momentum: Experiments have proven that nuclei with even mass numbers have an angular momentum equal to an integer, meaning that: I = 0, 1, 2, 3….. for A = even

As for the odd mass number, it has a momentum equal to half an odd number, i.e.: I=□(1/2),□(3/2),□(5/2),…..For A=odd

While according to Prout's hypothesis, even (odd-odd) nuclei such as (_5^10)B must have angular momentum equal to odd number multiplied by half and for odd nuclei, but they are even atomic number and odd n such as (_4^9)Be angular momentum equal to integer while in fact And the experiment proved the opposite. According to Prout's hypothesis, the nucleus of nitrogen-14 is made up of 14 protons and 7 nuclear electrons, meaning that the number of particles inside it is 21. This means that the angular momentum of the nucleus of N-14 is equal to an integer multiplied by half ħ, while the angular momentum of the nucleus of N-14 is 1ħ as demonstrated in practice, which indicates the failure of the Prout hypothesis. In fact, the nucleus of nitrogen-14 is composed of 7 protons and 7 neutrons, and since s_n=s_p=1/2 ħ, then S=0,1,2,…7ħ and practically S=1ħ Also, this hypothesis fails to explain the magnetic moment.

Nuclear charge

The charge of the nucleus is attributed to the charge of its protons, since neutrons have no charge, so it is equal to the atomic number (Z) multiplied by the charge of the proton, which is (qp = -e = +1.6×10-19C), meaning that:

$$Q_{Nu} = Z\, q_p = +1.6\times10^{-19}\, Z$$

That is, the nuclear charge is the sum of the charges of the protons in the nucleus

Nuclear Density

It is known that the mass of a nucleon (proton or neutron) is greater than the mass of an electron (mn = 1837me), so the nuclear density (ρnucleus) will be high.

1u = 1 a.m.u = 1.66 * 10-27 kg = 931 MeV

Mnucleus = A * 1.66 * 10-27 kg

$\rho_{\text{nucleus}} = \frac{\text{Mnucleus}}{\text{Vnucleus}} = \frac{A * 1.66*10^{-27}}{\frac{4}{3}\pi R_0^3 A} = \frac{1.66*10^{-27}}{(3.14)(1.25*10^{-15})^3} \times \frac{3}{4} \cong \boldsymbol{1.49*10^{18}}$ kg/m^3

Angular momentum of the nucleus:

The nuclear angular momentum is one of the important quantities in the nuclear structure, which affects all the kinetic nuclear properties (Dynamic properties). Orbital angular momentum) as a result of its movement inside the nucleus, and since the angular momentum is a directional amount, so the total angular momentum of the nucleus is the directional sum of the intrinsic and orbital angular momentum of nucleons in an appropriate manner. And the angular momentum of the nucleus is determined in terms of the quantitative number J. Practically also, complex nuclei have angular momentum equal to ($I\hbar$), where (I) is an integer including zero for nuclei in which (A) is even, meaning that there is a 2J+1 probability of direction of angular momentum, that is:

I = $0\hbar$, $1\hbar$, $2\hbar$, $3\hbar$, …….

Nuclear terms: There are some terms in nuclear physics, including:

1- Nuclide: a specific nuclear element that contains (Z) protons and (N) neutrons, and the most common symbol to represent a nuclide is (AzX).

2- Isotopes: nuclear elements with equal atomic number (Z) and different number of neutrons (N) and accordingly differ from each other by mass number (A), such as:

- Sodium isotopes

3- Isotones: nuclear elements with equal number of neutrons (N) and different atomic number (Z), :

4- Isobars: nuclear elements with equal mass number (A) and differing in number of neutrons (N) and atomic number (Z), such as:

5- Isomer: nuclear elements in an excited state with a relatively long life that can be measured and indicated by the symbol:

6- Nucleon: is the name given to a proton or neutron.

8- Positron: It is the anti-electron and has the same properties as the electron, but its charge is positive

Chapter II

Nuclear structure

The nucleus includes two groups of similar particles, the protons and neutrons, and each of these two groups is distributed separately from the other at specific energy levels according to the Pauli singularity rule, and each nucleon has a self-angular momentum called (self-spinning) (S), and there is a relationship between motion The orbital (L) and the autospin (S) for each nucleon such that the total angular momentum of the nucleon is (J = L + S) and the nuclear force between any two nucleons strongly depends on the relative directions of their spin.

Nuclear Binding energy

The difference between the real mass of the nucleus and the sum of the masses of its components from the nucleons individually is called the nuclear binding energy (which is measured in atomic mass unit) amu) or it is the amount of work needed to decompose the nucleus (A,Z) into nucleons and vice versa it is the energy that is released when nucleons are combined To form a cohesive nucleus:

$$M(A,Z) = ZM_p + NM_n - B.E$$

$$M(A,Z) = ZM_p + NM_n - B.E/c^2$$

$$B.E = [(ZM_p + NM_n) - M(A,Z)]c^2$$

$$\boldsymbol{B_{tot}(A,Z) = [\, ZM_p + NM_n - M(A,Z)]c^2}$$

Nuclear separation energy (S):

The double effect is not limited to the stability and abundance of nuclei, but also affects the energy of separation of a nuclear particle (p proton, neutron n, deuteron , triton and α particle (which is defined as the work needed to separate a particle or group of particles from One or more nuclei, or it is defined as the amount of work needed to separate a proton, neutron, detron, or alpha particle from the nucleus and, conversely, this amount of energy will be released when the nucleus captures one of these particles and expresses the neutron separation energy (S_n) by the relationship:

$S_n = [M(A-1,Z) + M_n - M(A,Z)]c^2$ ----------(1)

$S_n = B_{tot}(A,Z) - B_{tot}(A-1,Z)$ --------(2)

$S_{2n} = [M(A-2,Z) + 2Mn - M(A,Z)c^2$ ---------(3)

Or $S_{2n} = B_{tot}(A,Z) - B_{tot}(A-2,Z)$ ---------(4)

$S_p = [M(A-1,Z-1) + M_p - M(A,Z)]c^2$ ---------(5)

$S_p = B_{tot}(A,Z) - B_{tot}(A-1,Z-1)$ ----------(6)

$S_\alpha = [M(A-4,Z-2) + M_\alpha - M(A,Z)]c^2$ -------(7)

$S_\alpha = B_{tot}(A,Z) - B_{tot}(A-4,Z-2) - B(4,2)$ ----(8

$B(A,Z) = [ZM_p + NM_n - M(A,Z)]c^2$ -------(a) also:

$B(A-1,Z) = [ZM_p + (N-1)M_n - M(A-1,Z)]c^2$ --------(b)

$M(A,Z)c^2 = (ZM_p + NM_n)c^2 - B(A,Z)$

$M(A-1,Z)c^2 = [ZM_p + (N-1)M_n]c^2 - B(A-1,Z)$

$S_n = [ZM_p + (N-1)M_n]c^2 - B(A-1,Z) + M_n c^2 - [(ZM_p + NM_n)c^2 - B(A,Z)]$

$S_n = \cancel{N}M_nc^2 - \cancel{\mathbf{M_n c^2}} - B(A-1,\cancel{Z) + \mathbf{M_n}}\cancel{\mathbf{c^2}} - NM_nc^2 + B(A,Z)$

$$\boxed{S_n = B(A,Z) - B(A-1,Z)}$$

$B(A-1,Z-1) = [(Z-1)M_p + NM_n - M(A-1,Z-1)]c^2$

$M(A-1,Z-1)c^2 = [(Z-1)M_p + NM_n]c^2 - B(A-1,Z-1)$

$S_p = [(Z-1)\mathbf{M_p} + NM_n]c^2 - B(A-1,\cancel{Z-1}) + \mathbf{M_p\ c^2} - [(ZM_p + NM_n)c^2 - B(A,Z)]$

$$\boxed{S_p = B(A,Z) - B(A-1,Z-1) \quad \text{----------(6)}}$$

$B(A-4,Z-2) = [(Z-2)M_p + (N-2)M_n - M(A-4,Z-2)]c^2$

$M(A-4,Z-2)c^2 = [(Z-2)M_p + (N-2)M_n]c^2 - B(A-4,Z-2)$

$M(4,2)c^2 = (2M_p + 2M_n)c^2 - B(4,2)$

Example: Calculate the binding energy of the Detron if you know:

.(M_d =2.0141 amu , M_p =1.007825u , M_n=1.008665amu)

Sol.: $B_{tot}(A,Z) = [ZM_p + NM_n – M(A,Z)]c^2$

B(2,1) = [1*1.007825 + 1*1.008665- 2.0141] 931.48 = 2.23 MeV

Nucleon binding energy:

It is the rate of binding of any of the nucleons inside the nucleus, whether they are protons or neutrons, or it is also known as (the rate of energy required to liberate one of the nucleons of the nucleus).

The total binding energy Btot can be calculated practically from precise measurements of the mass M by mass spectrometer or from calculating the separation energy S from the study of nuclear reactions. Except in the light cores. If we assume that the binding energy between each nucleon and another is approximately a constant amount of C, then the nucleus containing A of the nucleons will contain (A(A-1)/2) of the interacting pairs, meaning that:

$B_{tot}(A,Z) \simeq \frac{1}{2} CA(A-1)$

$B_{ave} = \frac{B_{tot}(A,Z)}{A} = \frac{1}{2} C(A-1)$

From this result, we note that the average bonding energy of each nucleon Bave is directly proportional to the mass number A, but practical studies do not support this as Bave is almost constant except for very light nuclei. The saturation is approximately at four nucleons or more, and since the nuclear force is radioactive and the interaction of nucleons is limited to neighboring nucleons, the short range nuclear force, then, its effect is shorter than the radius of any nucleus except for light nuclei, which is within (2F), and this is what We got it from knowing the deuteron binding energy.

Separation energy

The ideal regularities of the neutron separation energies Sn as a function of the number of neutrons and shown in the figure below, we find that (at a certain value of the atomic number Z of a nucleus, the separation energy Sn is greater in nuclei in which N is even than in nuclei where N is odd), and that the The separation decreases with the increase in the number of neutrons, as well as for a certain value of the number of neutrons N, the Sp is greater in nuclei in which Z is even than in nuclei with odd Z, and such observations were observed and diagnosed practically with respect to the proton separation energy, Sp.

This is due to one of the properties of the nuclear force that results in an additional bonding between each pair of similar nucleons (n,n) (p,p) in the same state and which have a total angular momentum operating from opposite directions and it is called the pairing effect This is also the reason for the high stability of the α-particle structure

The basic theories about the nature of the nucleus:

In the absence of detailed information about the nuclear force, the description of the nature and composition of the nucleus remains within the framework of models that attempt to explain the phenomena observed in the nuclei. So far, there are no comprehensive and accurate models to describe the nuclear structure and nuclear force. It is worth noting that there are many of these models, including:

1- liquid-drop models 2- Shell model

3- Collective models 4- Kinetic distortion model

5- Interacting boson model (IBM

6- Optical model 7- Statistical model

8- cluster model, or α-particle model, and others.

There are many models that cannot be mentioned, and each of these models has success in some aspects and failure in others. We will talk about the first two models because they are the most successful models in explaining many of the nuclear properties.

1- Liquid-drop model or quasi-positional formula for binding energy:

Bohr proposed this model in 1937 to explain some nuclear physical phenomena such as radioactivity and nuclear fission and the derivation of the nuclear binding energy equation, but it does not describe the movement of nucleons inside the nucleus nor how they interact with each other.

From naming the model, it is clear that the nucleus has been likened to a drop of liquid. The justifications for the naming and the reasons for suggesting the model are:

1- Just as the size of a liquid drop increases with the increase in the number of liquid molecules, we notice that the size of the nucleus also increases with the increase in the number of its nucleons, that is, the greater the mass number A according to the relationship:

$$R = R_o A^{1/3} \rightarrow V = \frac{4}{3}\pi R^3 \rightarrow V = \frac{4}{3}\pi R_0^3 A$$

2- Evaporation of liquid corresponds to the phenomenon of radioactivity or nuclear emission, so the escape of part of the liquid particles from the drop corresponds to the emission of α and β particles from the nucleus.

3- The splitting of a large drop of liquid into two small drops corresponds to the phenomenon of nuclear fission (which is the phenomenon of splitting a heavy, unstable nucleus by bombarding it with a neutron, for example, into two nuclei close by mass.

This model was developed by Weizsacker in 1953, and it is a very approximate model in which the precise properties of the nuclear forces are neglected, but the attraction between nucleons is confirmed. Which collects a drop of liquid together, as it can be considered similar to a drop of incompressible liquid with a high density (104 gm/cm3). This formula is based on the following hypotheses proposed by Bohr:

1- The nucleus consists of an incompressible material with a radius R proportional to A1/3, meaning that:

$$R \propto A^{1/3}$$

2- The nuclear force that connects two nuclei does not depend on their charge, that is, it is equal for all nucleons, and therefore it does not depend on being protons or neutrons (that is, the force between P - P and n - n and p - n are equal).

3- The nuclear force has a very short range, and it is fixed within the range of its influence, that is, it is saturated. The state of the nuclei in the nucleus is very similar to the state of molecules in liquid substances, which are almost completely affected by their components only, and they move almost freely while maintaining a constant distance. This explains to us this similarity between the nucleus and the drop of the liquid, which prompted us to call this model the drop model. the liquid.

The formula is based on the following considerations:

1- Volume energy Ev: The largest part of the bonding energy of the nucleus is the part that is proportional to the mass number A, since the size of the nucleus is proportional to the mass number A, and this part is called the volume energy Ev.

$E_v = a_v A$ ----------(1)

2- Coulomb energy: Ec (coulomb energy) between protons, which is equal to the potential energy in the presence of Z of protons, reduces the binding energy

$E_c = -\frac{3}{5} Z(Z-1)\frac{e^2}{R}$ But $R = R_o A^{1/3}$

$E_c = -\frac{3}{5R_0} Z(Z-1) \frac{e^2}{A^{1l3}}$, $a_c = (3/5)(e^2/R_o)$

$E_c = -\frac{3}{5R_0} Z(Z-1) \frac{e^2}{A^{1l3}}$, $a_c = (3/5)(e^2/R_o)$

$E_c = -a_c(Z(Z-1)/A^{1/3})$ ---------(2)

3-Surface area energy Es: To consider all particles interacting with the total number of particles with the same effect is unrealistic.

Es ∝ 4πR2 , R = RoA1/3

Es = 4πRo2A2/3

Es = -asA2/3 ---------(3)

According to the above relationship, the number of nuclei surrounded by a number of nuclei less than 12 is proportional to A2/3 and this characteristic reduces the energy of the nucleus interconnection by the previous amount and this energy plays an important role in the case of light nuclei.

4- Assymmetry term Ea

It has been practically found that in the case of two isobars whose mass numbers are even, the isobar in which = A/2 Z = N is more stable than the isobar in which N≠Z, and this means that the inequality of the proton number Z and the neutron number N works to reduce the nuclear binding energy of isobar, for example The binding energy of isobar R (_8^16)O is greater than the binding energy of isobar (_7^16)N, and the assymmetry energy is defined as the difference between the nuclear energies of a nucleus in which the number of Z protons and neutrons is N such that Z≠N and the isobar nucleus have the number of each Protons and neutrons N = Z = A/2, or it is the difference between the binding energy of two isobars, one of which has N = Z = A/2 and the other is Z≠N, ie: E_a=B(A,Z=N=A/2)-B (A,Z≠N)

It was found when building the first nucleus from the second that υ of protons must be converted into neutrons, ie:

N=A/2 +υ , Z=A/2 -υ

Or υ = N-1/2 A=N-(Z+υ)=N-Z-υ

2υ=N-Z → υ = 1/2 (N-Z)

$$E_a = - a_a(A-2Z)^2/A = -a_a(N-Z)^2/A \qquad ----------(4)$$

5- Pairing term Eδ

It has been practically found that the bonding between two nucleons of the same type (p,p) or (n,n) is the greatest when the angular momentum of each of them is the greatest possible, equal in magnitude and opposite in direction to the other, and the double effect makes the nuclei (even-even) more abundant and stable From nuclei (even - odd) or vice versa, or odd-odd nuclei. Also, the nuclei in which N = Z are more stable, which are represented by light nuclei, and the number of N > Z in heavy nuclei, which makes them more stable, and this is why we put the limit $E\delta$, which represents the energy of pairing and depends On the type of nucleus, its value is 0 or $\mp$ 33/A^(3/4) and its value is zero when A is odd and the positive sign of even-even nuclei and the negative sign of odd-odd nuclei.

If A is the mass number of an even-odd or even odd nucleus, and A+1 is the mass number of an even-odd nucleus, and A-1 is the mass number of an even-odd nucleus, then the pairing effect term can be written in the equation: - B(A) E_δ=(B) A-1)+B(A+1))/2

6- Shell term (Tsh): shell term (shell filling effect limit):

It has been practically found that nuclei in which N = Z = magic number are stable and have high binding energy. If N or Z or both are close to a magic number, it causes an increase in binding energy, so to take this effect into consideration, it must be represented by a limit in the binding energy equation Nuclear and practically found to be equal to: Tsh = 1→3MeV

Tsh = 3MeV for Z=N = magic no. for example: 42He2 ,168O8

Tsh = 2MeV for Z or N = magic no. for example:158O7 ,157N8

Tsh = 1MeV for Z and N = no magic no. for example: 199F10

Therefore, the final form of the binding energy becomes:

Btot (A,Z)= avA-asA2/3-ac(Z(Z-1)/A1/3)-aa((N-Z)2/A)∓δ+ Tsh 1→3

Or: B(A,Z) =14A-13A2/3- (0.72Z(Z-1))/A^(1/3) - (20(NZ)^2)/A ∓33/A^(3/4) + Tsh 1→3

The values of the constants ap, aa, ac, as, av are experimental constants and depend on how to interpret the effect of each term. Therefore, we find different values for these constants, including:

av=14 , as=13 , ac=0.60 , aa=19 , δ=34/A3/4

av=16 , as=18 , ac=0.72 , aa=23.5 , δ=11/A1/3

In short, the liquid drop model was able to explain some nuclear interactions within energies that do not exceed 100 MeV, but it failed to explain interactions that exceed this value, and it could not explain some nuclear properties such as angular momentum and magnetic moments.

The liquid drop model confirms the cooperative effect of a large number of nucleons in the nucleus and is a basis for collective models.

2- Shell model

This model is one of the most important theories about nuclear structure, and the justifications for its emergence are:

A- Many of the properties of the nucleus seem to change periodically or to form a sudden discontionty at certain pairwise values of protons or neutrons. (, 20, 28, 50, 82, 126), and this was explained by the fact that these numbers form saturated (closed) covers.

2-Shell model with spin-orbit coupling

Mayer and Jensen, Suess (1949), have postulated. Haxel. There must be a strong interaction between the orbital angular momentum and the self-spinning of each nucleon in order to explain the phenomenon of the appearance of closed levels 2, 8 and 20 in the harmonic and square spherical oscillating voltage depression and the absence of levels 28, 50, 82 and 126. As a result of this interaction, the total momentum J is:

$J=l+S$ i.e $J = l + 1/2$ or $J = l - 1/2$

Each level is separated into two secondary levels, and the level with great momentum takes the lower level of energy (Hund's rule). After this assumption, the closed levels appeared 2, 8, 20 and 126.82.50.28 as shown in Figure (2).

The lowest state in the level of the cortex should be filled to the extent (2J+1) of similar particles except for states that are very close to each other or in fact they may exchange positions and thus competition between them occurs. So far we have taken into consideration 1- the attraction between one nucleon and the rest of the other nucleons 2- the spin and orbital interaction of each nucleon. These two factors represent the largest part of the interaction energy, and as is the case in atomic physics, there are residual interactions between the particles in each case (Secondary crust) It is observed in the last secondary crust only if it is partially filled. Since all completely filled planes give only zero angular momentum to the nucleus and give it positive symmetry, the angular momentum and ground state symmetry of the nucleus are determined by the remaining interactions only.

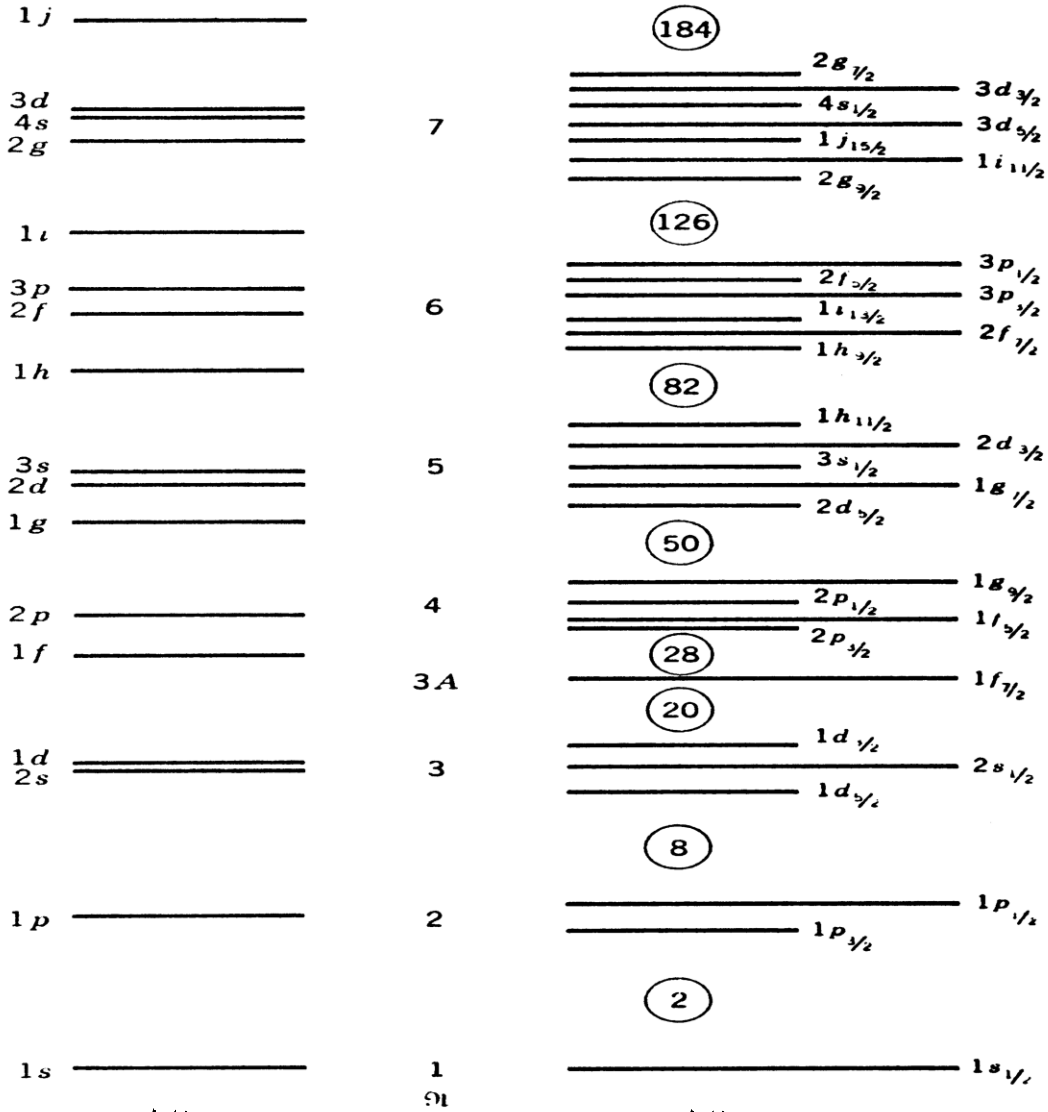
We also note from the study of atomic masses that the energy of separating a pair of neutrons is greater than twice the separation energy of a single neutron. The same goes for protons. The difference, which is the coupling energy, is about 1⇾2 MeV and represents the bulk of the remaining interactions. It appears that the coupling energy results from the fact that when there are two nucleons from a secondary shell that have opposite values -ι<mj>ι, the two wave functions combine and since the potential between them is a potential Gravitational attraction leads to a more bound state for the nucleus. Because of this pairing energy, an even number of similar nucleons in a partially filled secondary shell form pairs. The amount of angular momentum that it gives to the ground state is o+. If the number of neutrons or protons in the secondary shell is odd, then one These particles will remain non-dual because these considerations lead to the following rules in the way of calculating the angular momentum and symmetries of the ground nuclear states:

1- Even-even nuclei have the total angular momentum of the ground state is J=0+, and there is no exception to this rule.

2- Odd nuclei in which N or Z odd have angular momentum in the ground state equal to the momentum of the unpaired nucleon (proton or neutron) and its symmetry is 〖(-1)〗 ^l.

- For odd-odd nuclei, the angular momentum is equal to one of the values of Jp+Jn and |Jp-Jn| And its total angular momentum is the vector sum of the J values of each of the single proton and lone neutron, that is: J = jp + Jn

Thus, the quantum number J is an integer between: |Jp-jn|≤ J ≤ jp+jn



l,s بدون تفاعل A l,s فاعل **B**

Figure A represents the non-spin-orbit interaction and Figure B represents the spin-orbit effect on the splitting of levels with L > 0

The measured practical values of the angular momentum of the ground nuclear states provide a more accurate test of the shell model than that provided by the magic numbers.

The lowest state in the crustal plane must be filled to a limit (2j+1) of similar particles (that is, each plane is occupied by (2J+1) nucleons) and according to this relationship we get nLJ and the total number of occupancy is 2(2l+1) of nucleons.

In the case of even-pair nuclei, the protons and neutrons are in the form of pairs, so the spin and orbital momentum of these nuclei cancel each other out, and this result is consistent with practical observations that the total angular momentum of even-pair nuclei = zero.

Chapter two questions

1amu= 1u=$1.66043 *10^{-27}$ kgm

$M_0 c^2 = 931.478$ MeV

$M_p=1.6725*10^{-27}$ kgm =1.00727663 amu

$M_pc^2 = 938.256$ MeV

M_H(hydrogen atom) = 1.007825 amu

$M_n = 1.67482*10^{-27}$ kgm =1.0086654 amu

$M_nc^2= 939.550$ MeV

Example 1: If you know that: Mn = 1.0086654 amu and MH = 1.007825 a.m.u and M(2,1) = 2.014100 a.m.u, find 1- the total binding energy 2- the average binding energy 3- the packing fraction?

1- $B_{tot}(A,Z)=[M_H*Z+M_nN-M(A,Z)]c^2$

$B_{tot}(2,1)=[(1.007825*1) +(1.008665*1) –(2.014100)]\ 931.48 =2.23MeV$

2- $B_{ave}= \frac{Btot(A,Z)}{A} = \frac{2.23}{2} = 1.115MeV$

3- F = (M(A,Z)-A)/A = (2.014100-2)/2 = 0.0141/2 = 0.00705

Example 2: Calculate the separation energy of the neutron of a nitrogen atom 157N if you know that M(15,7)=15.00108 M(14,7)=14.00307 in units of a.m.u?

$S_n=[M(A-1,Z)+M_n-M(A,Z)]c^2$

$S_n=[14.00307+1.008665-15.000108]931.48 = (\quad)$

Ex3: Calculate the separation energy of ∝- particle from $^{11}_{5}B_6$ 1-in terms of mass 2- in terms of B.E .

Sol: 115B6 - 42He2 = 73X4 = 73Li4

Ex4: Calculate the B.E $_{ave}$ mass excess and packing fraction of: $^{12}_{6}C$, $_{2}He$.

Example 5: If you know that the mass of the nucleus of $^{7}_{3}Li$ is 7.016004 a.m.u, calculate:

1-The binding energy between the particles inside the nucleus is measured in joules   2- Average binding energy.

Binding energy can also be defined as the energy equivalent to a decrease in weight.

The solution:

$B_{tot}(A,Z)=\Delta E= 931[(1.0081437)Z+1.0089830(A-Z)- M(A,Z)]MeV$

$= 41.304754MeV=41.304*10^{6}ev$

$1ev = 1.6*10^{-19}\ J$

$\Delta E= 41.30 *10^{6}*1.6*10^{-19}\ Joule= \qquad *10^{7}\ erg$

Chapter III

Nuclear reactions:

In the period between 1919 when Rutherford announced his discovery of the industrial nuclear reaction

$$^{4}_{2}He + ^{14}_{7}N \longrightarrow ^{1}_{1}H + ^{17}_{8}O \qquad ...(1)$$

In 1939, when the news of the discovery of nuclear fission was announced by (Hahn and Strassman, Meitner and Frisch) on the one hand, and Meitner and Frisch on the other, all nuclear processes that could be provoked by nuclear bombardment with an energy of up to 10 MeV were identified. History The energy of projectiles has been increased to about (10 GeV) as a large number of nuclear reactions have been detected.

Through the study of radioactivity, it was possible to obtain many information related to nuclear structure, and another way to obtain this information is by studying the effect of bombing a nuclear target with a torrent of nuclear particles or gamma rays, and then studying the effect of bombing on the composition of the nuclei. This process is called (nuclear interaction) and is defined as a process During which the structure or energy of the target nucleus changes and the nucleus is bombarded with a nuclear particle or rays, as the aim is to study nuclear spectra, and there are two types of nuclear fusion or fission. Note that the composition of the nucleus changes when the nucleus suffers spontaneous radioactive decay by alpha or beta decay and vice versa. The nucleus is bombarded with nuclear particles of a certain energy.

Detailed theories of nuclear reactions have been developed based on two seemingly contradictory models of nuclear structure, the liquid drop model and the shell model.

One theory assumes that a nuclear projectile that hits the nucleus will interact strongly with all the nucleons in it and share the energy they carry with them so that this process takes place quickly and that the new nucleus formed by this process will decay in a way that does not depend on how it was produced.

As for theories that depend on the shell model, they assume that the fallen nucleon will interact with the nucleus by interacting with the effort of the shell model and that the probability of its absorption to form a complex nucleus is small. These two trends in the study of nuclear reactions can be unified in one theory as well, which is that any nuclear reaction, according to Weskov's theory, can be accomplished in several sequential stages.

Application of conservation laws:

We suppose that the result of bombardment is the entry of a nuclear particle (a) into the nucleus (X), and the outcome of the reaction is the exit of a nuclear particle (b) leaving the nucleus (Y). This reaction can be written as follows:

$$a + X \longrightarrow b + Y \quad \ldots\ldots\ldots\ldots\ldots(2)$$

$$a + X \rightarrow b_1 + Y_1$$

$$Y_1 \rightarrow b_2 + Y_2$$

$$Y2 \rightarrow b3 + Y3 \quad \ldots\ldots(4)$$

Law of Conservation of Linear Momentum - Calculation of Reaction Energy:

$$M_a c^2 + T_a + M_x c^2 = M_b c^2 + T_b + M_y c^2 + T_y \quad \ldots..(5)$$

$$Q = T_b + T_y - T_a \quad \ldots\ldots..(6)$$

$$Q = [\, M_a + M_x - (\, M_b + M_y \,) \,]\, c^2 \quad \ldots\ldots\ldots\ldots(7)$$

$$Q + T_a \geq 0 \quad \ldots\ldots\ldots(8)$$

In the general case of a nuclear reaction, the particle b is fired in a direction that makes an angle $\boldsymbol{\theta}$ with the direction of the projectile a, and using the law of conservation of momentum and energy from the figure below, we get:

$$M_a v_a = M_Y v_Y \cos\varphi + M_b v_b \cos\theta$$

$$0 = M_Y v_Y \sin\varphi - M_b v_b \sin\theta \quad \ldots\ldots..(9)$$

$$(M_a T_a)^{1/2} - (M_b T_b)^{1/2} \cos\theta = (M_Y T_Y)^{1/2} \cos\varphi$$

$$(M_b T_b)^{1/2} \sin\theta = (M_Y T_Y)^{1/2} \sin\varphi \quad \ldots\ldots\ldots.(10)$$

$M_aT_a -2(M_aT_a M_bT_b)^{1/2} \cos\theta + M_bT_b = M_YT_Y$ …….(11)

$$Q = T_b(1+\frac{M_b}{M_Y}) - T_a(1-\frac{M_a}{M_Y}) - \frac{2}{M_Y}(M_a\mathrm{T_a}M_bT_b)^{\frac{1}{2}}\cos\theta$$

Types of nuclear reactions:

Nuclear reactions can be classified according to the bombardment particle, the bombardment energy, the target nucleus, or the reaction products. We can classify the reaction according to the bombardment particle into:

1- Charged-particle reactions resulting from protons (P), detrons (d), and alpha particles (α), (C^{12}), and (O^{16}). The second and third reaction is called the reaction of heavy ions.

2 - Neutron reaction.

3 - Photo nuclear reactions resulting from gamma rays.

4- Electron-induced reactions.

Nuclear reactions can also be classified according to the bombardment energy, as follows:

1 - Thermal energies (eV) (Thermal energies ≈).

2 - Thermal energies (Epi Thermal energies ≈1eV).

3 - Slow neutron energies ≈ 1 keV.

4 - Fast neutron energies ≈ 0.1-10MeV.

5 - Low-energy charged Partiches ≈0.1 - 10MeV.

6 - High energies (High - energy ≈ 10 - 100 MeV).

The classification according to the nucleus of the target:

1 - Light nuclei, if $A \le 40$.

2 - Medium-weight nuclei, if $40 \prec A \prec 150$.

3 - Heavy nuclei, if $A \ge 150$.

If the light particle resulting from the reaction is identical to the bombarded particle in terms of type and energy of the center of gravity, then the reaction in this case is called elastic scattering, i.e. (Y=X,b=a) and it is expressed as (X(a,a)X), for example. on it:

$$^{26}Mg + P \longrightarrow {}^{26}Mg + p$$

It is expressed by the symbol (^{26}Mg (p,p) ^{26}Mg) and the nucleus is (^{26}Mg) in the ground state. This form of nuclear reactions is called dispersal or volatilization.

But if the nucleus (^{26}Mg) is left in an agitated state, this type is called inelastic scattering, and the nucleus returns to its ground state by emitting gamma rays, and this is called the trap reaction.

In the event that the products of the reaction have similar masses, we call the reaction (the fission reaction).

Forms of nuclear reactions:

First: scattering or volatilization: in this case, it is (Y = X, b = a) and is expressed by the symbol (X (a, a) X). The projectile (a) is in the form of a nucleon or in the form of a light nucleus such as a detron or an alpha particle. That the bombardment energy of the charged projectile is sufficient to overcome the electrostatic Coulomb potential in the nucleus.

$$^{26}Mg + P \longrightarrow {}^{26}Mg + p$$

Second: the nuclear reaction (P, α) In this, the resulting channel (the right end of the reaction b + Y) is not equal to the primary channel (a + X). For example:

$$^{26}Mg + p \longrightarrow {}^{23}Na + \alpha$$

Third: Radioactive trap: In this case, the nucleus captures a low-energy nucleon and produces a compound nucleus in a state of high irritation and returns to the ground state by emitting gamma rays, as in the two examples:

$$^{26}Mg + p \rightarrow {}^{27}AL + \boldsymbol{\gamma} \quad \text{or} \quad {}^{14}N\ (P,\gamma)\ {}^{15}O \text{ or } {}^{15}O^{*}$$

This is called the proton capture reaction

Fourth: Photon destruction: In this case, the nucleus is bombarded with high-energy electromagnetic rays, such as gamma rays, and then fragments of the nucleus, such as nucleons, deuterons, or alpha particles, fly off, as in the interaction:

$^{27}AL\ (\boldsymbol{\gamma},P)\ ^{26}Mg$, $^{27}AL + \boldsymbol{\gamma} \rightarrow {}^{26}Mg + P$, $^{14}N\ (\boldsymbol{\gamma},P)\ ^{13}C$ or $^{13}C^*$

This reaction is also called photonuclear reaction.

From this we note that the photon decay and radiative trap are opposite processes.

Fifth: Induced nuclear fission: When the nucleus is captured, a nucleon turns into a very heavy, excited nucleus and splits into two closely spaced fragments. This process is followed by the release of a number of neutrons, as in the equation:

$^{234}{}_{92}U + n \rightarrow\ \ Y_1 + Y_2 + 3n$

Nuclear fission:

In 1939, Hahn and Strassman discovered a new method for producing alkaline elements by irradiating uranium with neutrons. To explain this phenomenon, Maines and Fresh suggested that the process of absorbing neutrons by uranium makes the uranium nucleus in a very agitated state that leads to its splitting into two fragments of close masses.

Nuclear fission is another type of nuclear reaction, and it can be analyzed according to the liquid drop theory. Then the spherical, then the vertical oval, then the spherical, then the horizontal oval again, and so on

The conservative surface tension force always tries to restore the spherical shape of the drop, but the continuous movement of the particle makes it pass the regular spherical shape and take the opposite distorted shape. Considering that the nuclei behave like a liquid droplet with a surface tension, it will vibrate in the case of irritation like a liquid drop, and these nuclei are exposed to a long-range rupturing force resulting from the force of electrostatic repulsion between the protons inside the nucleus trying to tear the nucleus.

When the core deforms from the spherical shape, the short-term conservative force of the surface tension must counteract the long-term repulsive force as well as the inertial moment of the nucleus. If the degree of deformation is small, the surface tension force will be capable of both. The irritants are in the form of gamma rays.

But if the degree of distortion is very high, the surface tension force will not be able to restore the separated proton groups from each other in a long range to their original position, and the result will be the splitting of the nucleus into two halves, and the two new nuclei resulting from fission are called fragments:

Heavy nuclei have a greater ratio of neutrons to protons than light nuclei, meaning that they contain an increase in the number of neutrons.

Nuclear fission occurs when a heavy nucleus absorbs enough excitation energy of the order of 5 MeV to cause it to vibrate violently. Some specific nuclei, especially (23592U), as soon as they absorb one extra neutron, vibrate strongly to the point that they split into two halves, and other nuclei, such as (23892U), need more excitation energy than the bonding energy liberated during the process of absorbing one additional neutron for splitting and splitting occurs only when They bombard fast neutrons whose kinetic energy exceeds (1 MeV).

The process of nuclear fission can occur by excitation by other means in addition to neutron capture, for example by proton bombardment or gamma rays. The amazing thing about nuclear fission is the enormous energy released from fission. Where does this huge energy come from?

The answer to this enormous energy comes from the fact that the sum of the resulting masses is less than the sum of the interacting masses, so the lost masses are transformed into enormous energy according to Einstein's relationship. Chemical reactions A possible example of fission reactions is the uranium nucleus (23592U) by a slow neutron (n1) is the following:

$${}^{235}_{92}\boldsymbol{U} + {}^{1}_{0}\boldsymbol{n} \rightarrow {}^{141}_{56}\boldsymbol{Ba} + {}^{92}_{z}\boldsymbol{Kr} + \ \boldsymbol{x}{}^{1}_{0}\boldsymbol{n} + \boldsymbol{energy}$$

Nuclear fission is defined as an artificial nuclear reaction in which a relatively heavy nucleus splits to give two relatively light nuclei that are more stable than the fissioned nucleus.

Third chapter questions

Q1/ Define the reaction energy (Q) and then prove that

$$Q = T_b(1 + \frac{M_b}{M_Y}) - T_a(1 - \frac{M_a}{M_Y}) - \frac{2}{M_Y}(M_a \mathrm{T_a} M_b T_b)^{\frac{1}{2}} \cos\theta$$

Q2/ The uranium 235 nucleus splits when it is bombarded with a slow neutron according to the following reaction:

$${}^{235}_{92}\boldsymbol{U} + {}^{1}_{0}\boldsymbol{n} \rightarrow {}^{141}_{56}\boldsymbol{Ba} + {}^{92}_{z}\boldsymbol{Kr} + \ \boldsymbol{x}{}^{1}_{0}\boldsymbol{n} + \boldsymbol{energy}$$

1- Neutrons are usually used to bombard a uranium nucleus. Why? C because they are chargeless particles

$${}^{235}_{92}\boldsymbol{U} + {}^{1}_{0}\boldsymbol{n} \rightarrow {}^{141}_{56}\boldsymbol{Ba} + {}^{92}_{36}\boldsymbol{Kr} + \boldsymbol{3x}{}^{1}_{0}\boldsymbol{n} + \boldsymbol{energy}$$

3- Explain the sequential character of this interaction? 4- Calculate the energy produced by the reaction if you know that

$${}^{235}_{92}\boldsymbol{U} = \boldsymbol{234.9934u},$$

$${}^{92}_{z}\boldsymbol{Kr} = \boldsymbol{91.8973u} \ \ {}^{141}_{56}\boldsymbol{Ba} = \boldsymbol{140.9139u} \ \ {}^{1}_{0}\boldsymbol{n} = \boldsymbol{1.0087u}$$