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Studying of the Nuclear Properties for Some Rare Earth Elements Internal in the Production of Fiber Optical Laser

A Thesis

Submitted to physics Department / College of Education for Pure Science (Ibn Al-Haitham) / Baghdad University in Partial Fulfillment of the Requirements for the Degree of Master of Sciences in Physics

By

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بسم الله الرحمن الرحيم

يرفع الله الذين إمنوا منكم والذين أوتوا العلم درجات والله بما تعملون خبير

صدق الله العلي العظيم

(المجادلة / 11)

DEDICATION

With Love To

To my wife
And sons
Ahmed, Ebrahim and Aya ,Sama , Hadeer
My grandchildren Jani, Haei
To the owners of the known and the beautiful
Proff Dr. Ghassan Hamid Abdul Majid,
Assist Proff Dr. Samira Ahmed Ebrehiem,
And Proff Dr. Sameer A. Maki ,
Poffr Dr. Abdel-Jabbar Haseen ,
Dr. Kholoud, Assist Proff Hanadi,
and Assist.lecturer (Saif Alaa-
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To all my colleagues and researchers ***Abdul-Rahim, Hussein, Ayoub, Aseel*** *and* ***Inas.***

Sameer .

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Date: ١١ / ٩ / **2019**

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ABSTRACT

The present study focused on the study of nuclear properties of the nuclei for rare earth elements by calculating (interaction energies , threshold energy , the excess mass, Binding energy , the coulomb barrier and the proportion of packing), which tabled in the third chapter .

The rare elements have multiple levels of energy used in amplifying optical signals in fiber optical for the production of optical laser and with form better from known ancient techniques, this is due to their similarity in chemical properties because of its electronic structure from ($4f^{0}\,5d^{1}6s^{2}$) to ($4f^{14}\,5d^{1}6s^{2}$) which distinguished it from other elements, as referred to in the four chapter.

The nuclear reaction (α ,n) were studied for the nuclei of atoms rare individually numbers for elements:

($^{139}_{57}$La, $^{141}_{59}$pr, $^{159}_{65}$Tb, $^{165}_{67}$Ho , $^{169}_{69}$Tm , $^{172}_{71}$Lu), which alpha energies between (9.085 - 10.245) MeV, depending on the following nuclear reactions :

$$^{139}_{57}\mathrm{La}\,(\alpha,n)\,^{142}_{59}\mathrm{Pr}\,,\quad ^{141}_{59}\mathrm{Pr}\,(\alpha,n)\,^{144}_{61}\mathrm{Pm}\,,\quad ^{159}_{65}\mathrm{Tb}\,(\alpha,n)\,^{162}_{67}\mathrm{Ho}\,,$$

$$^{165}_{67}\mathrm{Ho}\,(\alpha,\mathrm{n})\,^{168}_{69}\mathrm{Tm}\,,\quad ^{169}_{69}\mathrm{Tm}\,(\alpha,\mathrm{n})\,^{172}_{71}\mathrm{Lu}\,.$$

Also the nuclei of atom ($^{144}_{62}$Sm),which is marital number element

$^{144}_{62}\mathrm{Sm}(\alpha,\mathrm{n})\,^{147}_{64}\mathrm{Gd}$, which energy of alpha about (12.253 MeV).

The cross-sections for the nuclear reactions mentioned above were calculated and the published in the international literature :

(EXFOR, ENDF, JENDL-3.0 , JEF-2.2, JEFF, CENDL-2).

For the selection of the appropriate energies in calculate ground-level interaction using a computer program (MATLAB 7.6.0 R 2008 a), and energy steps were (0.2 MeV) .

We get the derivation the equation semi -experimental and the results that linking cross-section change with certain energies was painted and tabulated , as noted in the third chapter .

Also the neutron yield it was calculated according to the Zeigler formula for previous neutron interaction using the program (SRIM 2013) by calculate the stopping power , which was tabulated and drawn with steps of (0.2 MeV), for rare isotopes that used in optical leaser which have many applications in in medical, industrial and military fields, agricultural and computers.

The cross-sections of the inverse reactions (n,α) were calculated for some of the target nuclei of (REEs) at the ground state and got the semi -empirical equation of the inverse sections, the results that obtained were tabulated and drawn to get the cross-section in direct method for the following reactions :

$^{142}_{59}\mathrm{Pr}(n,\alpha)^{139}_{57}\mathrm{La}$, $^{146}_{61}\mathrm{Pm}$ (n,α) $^{141}_{59}\mathrm{Pr}$, $^{147}_{64}\mathrm{Gd}\,(n,\alpha)^{144}_{62}\mathrm{Sm}$,
$^{162}_{67}\mathrm{Ho}\,(n,\alpha)\,^{159}_{65}\mathrm{Tb}$, $^{168}_{69}\mathrm{Tm}(n,\alpha)^{165}_{67}\mathrm{Ho}$, $^{172}_{71}\mathrm{Lu}(n\,,\alpha)^{169}_{69}\mathrm{Tm}$

Table Abbreviation

Abbreviation	Full name
IAEA	**International Atomic Energy Agency.**
NNDC	**National Nuclear Data Center.**
EXFOR	**Exchange Format Library (The international experimental).**
ENDF	**Evaluated Nuclear Data File-B-Version6 (USA).**
JEF	**Joint Evaluated File-Version 2.2(European).**
JEFF	**Joint Evaluated Fission and Fusion File -Version 3.0(European).**
CENDL	**Chinese Evaluated Nuclear Data Library-Version2.**
JENDL	**Japanese Evaluated Nuclear Data Library-Version3.2.**
BROWD	**Russian Evaluated Nuclear Data library Version 2.2.**
REEs	**Rare earth elements**
LREEs	**Light Rare earth elements**
HREEAs	**Heavy Rare earth elements**

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Chapter One

(1-1) Rare Earth Elements :

Lanthanide elements (Ln: La- Lu : 57–71) belong to the rare- earth series of elements which number (14) in addition to $_{21}Sc$ and $_{39}Y$ they present specific chemical, optical, and magnetic properties that are a consequence of their peculiar electronic structure, they have become essential to almost all aspects of modern life, the rare elements (REEs) are a group of 17 chemical elements which appear in the periodic table .The group consists of the (15) lanthanide (Ln) ($^{139}_{57}La$, $_{85}Ce$, $^{141}_{59}Pr$, $_{60}Nd$, $^{141}_{61}Pm$, $^{144}_{62}Sm$, $_{63}Eu$, $_{64}Gd$, $^{159}_{65}Tb$, $_{66}Dy$, $^{165}_{67}Ho$, $_{68}Er$, $^{169}_{69}Tm$, $_{70}Yb$, $^{172}_{71}Lu$)[1].

Have been divided into two groups, (LREEs) and (HREEs), the definition on the basis of electrons configuration of each rare-earth element as follows[2] :

a) The light rare earth elements (LREEs) from Lanthanum to Gadolinium have unpaired electrons in the 4f electron shell (0 to 7), the outer electron configurations for the solid state from ($4f^0 5d^1 6s^2$) to ($4f^7 5d^2 6s^2$).
b) The heavy rare earth elements (HREEs) from Terbium to Lutetium , have paired electrons in the 4f electron shell (7-14) (a clockwise and counter – clockwise spin election), the outer electron configurations from ($4f^7 5d^1 6s^2$) to ($4f^{14} 5d^2 6s^2$).

The energy of the 4f sub-shell falls below that of the 5d sub- shell, that means the electron beginning to fill the 4f sub- shell before the 5d sub-shell [2].

(1-1-1) Properties:

1- Rare earths typically occur in compounds as trivalent in carbonates, oxides, phosphates, and silicates, the lanthanides (also referred to as lanthanides) .

2- Be within the energy level 4f filled partially or completely, which makes it with multiple energy levels used in fiber laser technology and the lowest pumping power and the production of laser within the infrared area with high output power after achieving the requirement of catalytic emission and the reverse distribution of molecules[3].

3- Electronic arrangement of dust elements is not affected by the crystal structure of glass when vaccinated because their internal transitions are protected when used as an effective medium in optical fiber lasers.

4- The physical similarities in atomic radius ,the similar radii and oxidation states of the REEs allow for liberal sub situation of the REEs for each other into various crystal and charge between REEs lading to their separation as distinguishable elements[4].

(1-1-2) Minerals that containers:

REEs comprise significant amounts of many minerals, such as the carbonate bastnasite ($Ln CO_3 F$) , monazite ((Ln, Th) PO_4) , Euxenite ((Ln,Ca,U,Th) $(Nb,Ta,Ti)_2O_6$) , Samarskite $(Ln,U,Fe)_3$ $(Nb,Ta,Ti)_5 O_{16}$, Florencite ($LnAl_3(PO_4)_2(OH)_6$), Hydroxylbastnasite ($LnCO_3(OH,F)$), Fergusonite (Ln(Nb,Ti) O_4), Fergusonite (Ln (Nb,Ti) O_4) , Gadolinite ($LnFeBe_2Si_2O_{10}$), Aeschynite $(Ln,Ca,Fe,Th)(Ti,Nb)_2(O,OH)_6$, Ancylite $SrLn(CO_3)_2(OH).H_2O$, Loparite (Ln,Na,Ca) $(Ti,Nb)O_3$ [5].

(1-1-3) Rare earth elements used doped in optical fiber:

In the field of laser technologies, rare-earth doped materials can be used as gain media.

1- (Nd^{3+}: YAG), is formed from a mixed oxide system having a composition of ($Y_3Al_5O_{12}$) , Or Nd :YVO_4, and another type of neodymium laser is the (GSGG : Cr3 : Nd^{3+}) laser. It uses a crystal of gadolinium- scandium-gallium garnet, co-doped with chromium and neodymium ions.

2- Ce^{3+}, Yb^{3+} , Pr^{3+} , Dy^{3+} , Er^{3+} and Tm^{3+}used as hosts for the silica (SiO_5) such as (Ce^{3+}- Eu^{3+}) co-doped (Y_2SiO_5), (Er^{3+}) as in Germano – silicate, and (Yb^{3+}) ions in phosphate glasses host: (65P_2O_5 - 8Al_2O_3 - 27BaO + ZnO +Na_2O +MgO) [6].

3- Aluminosilicate glasses with low (SiO_2) content may be doped with a large amount of (Nd_2O_3).Anther hosts: (P_2O_5) such as phosphate glass was melted in accordance with composition: (65P_2O_5 - 8Al_2O_3 27BaO +ZnO + Na_2O+MgO),and the aluminosilicate with composition: (65P_2O_5 - 8Al_2O_3) glasses doped with (Nd_2O_3) or (Yb_2O_3)[7].

4- Fluoride glasses are a generally non-oxide range of glasses within this class sub- groups as fluorozirconate based on zirconium fluoride, fluoroaluminate glasses, based on aluminum fluoride, and fluorophosphates glass metaphosphate containing oxygen :

Fluoride glasses are often referred such examples are ZBLAN (ZrF_4-BaF_2 - LaF_3- AlF_3 - NaF), or ZBLA (ZrF_4 - BaF_2 - LaF_3 - AlF_3), and fluorozirconates from which the most common is the ZBLAN (ZrF_4- BaF_2, LaF_3, AlF_3,NaF), for example, (Pr^{3+}: ZBLAN) , and can be doped also into (YAG), and (Tm^{3+}: ZBLAN) (ZrF_4-BaF_2-LaF_3-AlF_3-NaF) [8].

5- (Tm^{3+}or Er^{3+}) doped fluoride or tellurite glass tellurite different from fluoride glasses in it being based mainly on a single molecule ,tellurite glass compositions include ($75TeO_2$ - 20ZnO - 5Na2O), and ($75TeO_2$ - 12ZnO -5PbO - $3PbF_2$ - $5Nb_2O_5$ [8] .

(1-1-4) Applications of the REEs:

- Used in Lasers and optical spectrophotometers, surgery, dentistry and fiber-optical communications and used in some of the most powerful magnets in the world, and used in cellular communications.
- Portable X-ray machines and metal halide lamps , used stabilizers for exotic light-weight jet engine turbines .
- Used as a dopant (along with holmium and chromium) in YAG lasers.
- To create a material that gives off laser light highly suitable to medical applications.
- Used Lasers green phosphors, fluorescent lamps and an application in medical X-ray machines, and magnetostrictive alloys.
- Sm is probably the most important, its radiation makes it an effective killer of cancer cells.
- Rare-earth magnets, violet colors in glass and ceramics.
- Used in hydrogen storage, battery- electrodes, hybrid cars and camera lenses , enters the industry in high-conductivity materials.
- Promethium can be used to make lasers that can be used to
- communicate with submerged submarines.
- It is used in infrared absorbing glass and as a neutron
- absorber in nuclear reactors.
- used in stress gauges to monitor ground deformations caused, for example, by nuclear explosions[9].

(1-2) Optical fiber laser:

LASER: " Light Amplification by the Stimulated Emission of Radiation". Ideal laser light is single-wavelength only. This is related to the molecular characteristics of the material being used in the laser. Solid-state lasers use a crystalline or glass rod which is "doped" with ions (Rare elements) that provide the required energy states, where the light is guided due to the total internal reflection in a single mode optical fiber are instead called fiber lasers. Erbium and ytterbium ions are common active species in such lasers and also neodymium is a common dopant in various solid-state laser crystals as well as the rest of the elements[10].

(1-2-1)The three electronic transitions in the laser wave emission:

1- Induced absorption :

Energy is supplied from outside(photon) and is absorbed by the atomic structure and became the electron is in excited state(higher energy), where : where , $E=h\nu = E_j - E_i$

such a transition to the higher state is called absorption.

2- spontaneous emission:

Electron in excited (higher energy) state needs to reach a stable state after a short period of time (10^{-8}s) accompanied by the emission of a photon whose energy is equal to the difference between the two levels, but the photons emitted are different in phase, direction, and energy .

3- Stimulated emission:

An incident photon on electron excited state and a transition from the higher to a lower energy state produces an additional photon , the incident photon is similar to phase,direction and energy. It is represents the key principle in laser operation is the principle of stimulated emission[11].

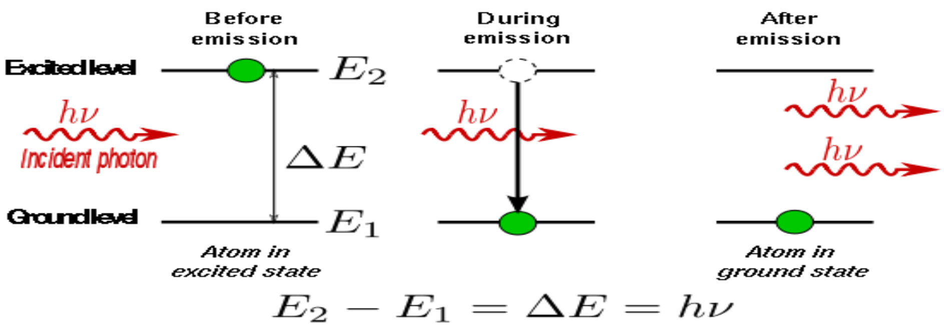


Fig.(1-1) This process is known as stimulated emission[11].

(1-2-2) Parts of laser (constituents of laser):

1- **Energy source** (usually referred to as the pump):

the pump source is the part that provides energy to the laser system, in order to achieve the state of the inverse distribution to ensure the generation of the laser. Examples of pump sources include electrical discharges, flash lamps, are lamps, light from another laser, chemical reactions[12].

2- **The active laser medium (also called gain medium):**

Is the source of optical gain within a laser, is a laser in which the active gain medium is an optical fiber doped with rare-earth elements.

They are related to doped fiber amplifiers , which provide light amplification without lasing , include: certain crystals, typically doped with rare-earth ions (e.g. neodymium , ytterbium , or erbium), in order to fire a laser, the active gain medium must be in a energy distribution known as a population inversion continuous ,must be create the cavity in

which the photons remain entrapped, something known as a fiber Bragg grating is added , is simply a section of glass which has stripes in it which is where the refractive index has been altered. Any time that light passes across a boundary between one refractive index and the next, a small bit of light is refracted back. essentially, the Bragg grating makes the fiber laser act like a mirror [12].

3- Optical resonator :

An optical fiber is a flexible filament of very clear glass capable of carrying information in the form of light. The two main elements of an optical fiber are its core and cladding.

The " core ", or the axial part of the optical fiber made of silica glass, is the light transmission area of the fiber, the " cladding " is the layer completely surrounding the[13]. In the field of laser technologies, rare-earth doped materials can be used as gain media .

The basic functional structure of an optical fiber consists of an outer protective cladding and an inner core through which light pulses travel.

The core is just about (2-10 µm) , (cladding) is about (125 µm) , (Buffer) a bout (245 µm) and diameter of the (Jacket) a bout 400µm[14].

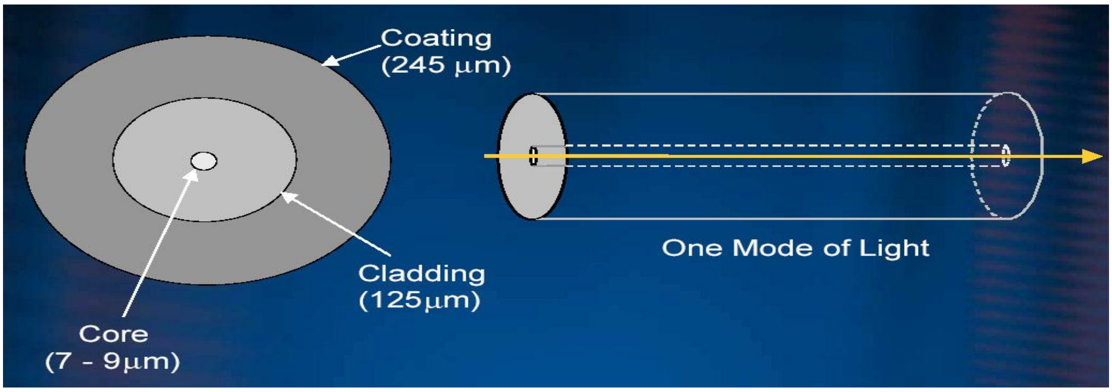


Fig.(1-2) The fiber consists of a core surrounded by a cladding layer [14].

If light is incident on a cable end with an angle of incidence greater than the critical angle , in this way, light travels very quickly down the length of the cable over a very long distance (tens of kilometers)[15].

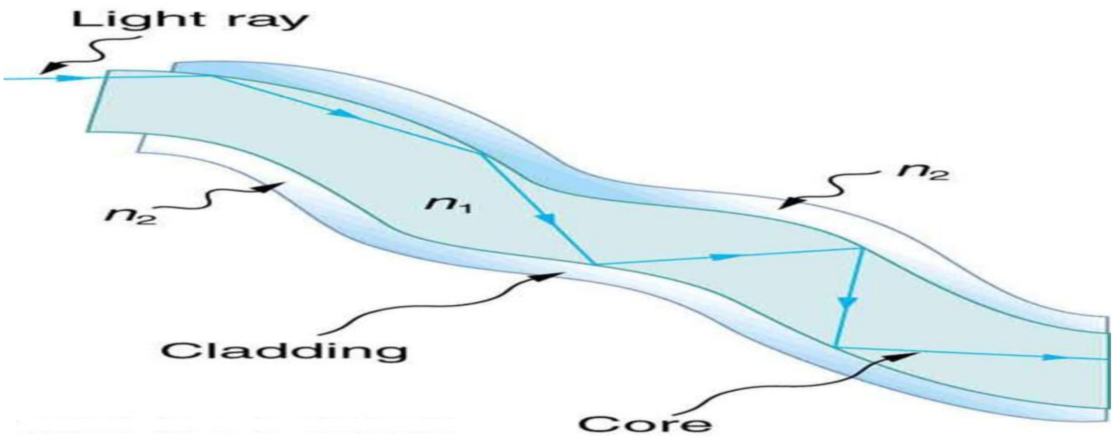


Fig.(1-3) The Phenomenon of Total Internal Reflection and Acceleration of Light in Fiber Optics [15]

Therefore, to propagate the light through optical fiber, the incident angle should be made higher than the critical angle at various points on the core ($\theta_1 > \theta_c$), the critical angle is used for the mathematical expression to the occurrence of total internal reflection as in[15] :

$$n_1 \sin \theta_1 = n_2 \sin 90^{\circ} (\text{ from Snellis law}) \ldots\ldots\ldots(1\text{-}1)$$

$$\sin \theta_1 = \frac{n2}{n1} \qquad (\text{ since, } \sin 90^{\circ} = 1)$$

$$\sin \theta_c = \frac{n2}{n1} \qquad (\text{ since, } \theta_1 = \theta_c)$$

$$\theta_c = sin^{-1} \left[\frac{n_2}{n_1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}2)$$

When the core diameter is single , said to be a single- mode fiber ,but fibers with large core diameters(50- 62.5) μm are multi-mode fibers[16] .

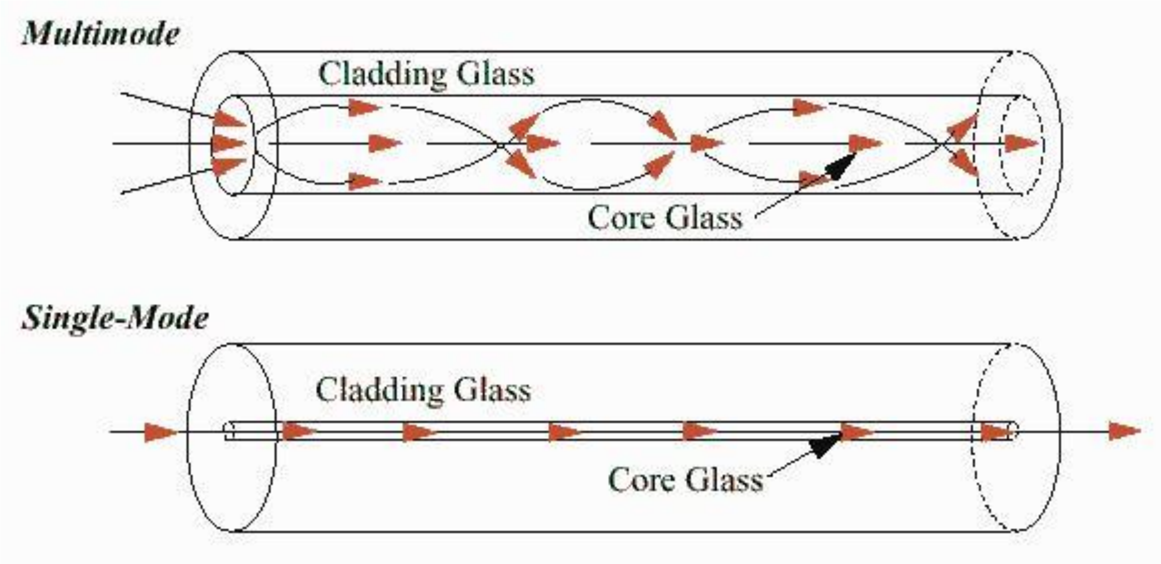


Fig.(1-4) Refractive-index , and typical rays in: (a) a multimode step-index fiber, (b) a single-mode step-index fiber**[16].**

(1-2-3) There are three important types of optical amplifiers :

1- The most significance for telecommunications uses is the silicate glass used to build (EDFA) (ytterbium doped fiber amplifier).

This operates as a 3-level system when pumped at (1520 to 1620) nm with possible (Eb^{3+} doping) , also with erbium (Er^{3+}) doped fiber amplifier (EDFA) pumped at (1530 to 1570) nm , and also the praseodymium (Pr^{3+}) doped fiber amplifier called (PDFAs) (Rare Earth Doped Fiber amplifiers) ,which do operate in the (1300 nm)[16] .

Another type of neodymium laser is the (GSGG: Cr3: Nd^{3+}) . It used a crystal of (gadolinium, scandium, gallium, garnet) , doped with (chromium and neodymium) about (1300 nm) band , and also crystalline hosts ($CeNiSi_2$ - type for La through Sm) or ($LuNiSn_2$ – type for Gd through Lu)[17] .

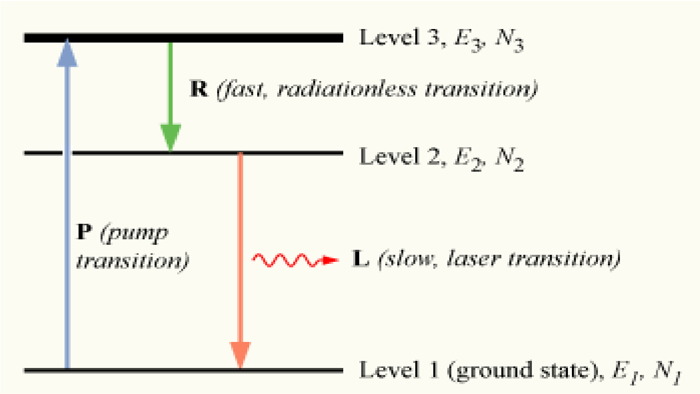


Fig.(1-5) A three-level laser energy diagram.[11].

Whose energy levels provide the basis for the population inversion and gain necessary for amplification of optical signals. An optical amplifier is a device which amplifies the optical signal directly without every changing , it to electricity. The light itself is amplified, and then converted to optical form again [17].

2- the semiconductor optical amplifier (SOAs),

3- the fiber Raman amplifier[17].

(1-3) Mechanisms of Nuclear Reaction:

The nuclear reaction is used to measure the nuclei properties, and nuclear scattering to measure quantum numbers of energy levels, transition ratio between the binding energy and excitation[18].

A process which occurs as an effect of reactions between atomic nuclei, when the interacting particles oncoming each other to within distances of the order at nuclear dimensions (10^{-12} cm)[19].

The energy should be high enough to defeat the natural electromagnetic repulsion between the protons, this energy "barrier" is called the Coulomb barrier[1]. If the energy is below the barrier, the nuclei will recoil off each other [18].

When a charged particle enters into a matter, it interacts with electrons or nuclei in the middle, these reactions are called "collisions", the collisions are lead to the :

(a) Ionizations : (productions of ion-electron pairs), and

(b) Excitations : (raising the energy of the orbital electrons into higher states in the atom[20].

The reaction products are also two particles (with the exception fission) the reaction is indicated as[21].

$$^{A1}_{Z1}x_1 + ^{A2}_{Z2}X_2 \rightarrow ^{A3}_{Z3}x_3 + ^{A4}_{Z4}X_4 \quad \text{or} \quad X\,(a\,,b)\,Y$$

where: x_1= bombarding particle, X_2 = target (at rest in the lab. system), x_3= light reaction product, X_4= heavy reaction product.

When a collision occurs between the accident particle and a target nucleus, either the beam particle scatters elastically outside the target nucleus in its ground state or the target nucleus is excited and then decays by emitting radiation or nucleons.

A nuclear reaction is described by correspond the incident particle, target nucleus, and reaction products [18].

Direct interactions proceed faster than compound-nucleus reactions, the time of direct interactions is given by the time needed by the projectile to enter the nucleus and the time needed to leave the nucleus after collision[22]. The direct reaction processes happen more quickly, in a time of **(**10^{-22} s) [23].

These reaction equations must be balanced, just as in chemical reactions must be [24].

$$ {}^{4}_{2}\mathrm{He} + {}^{14}_{7}\mathrm{N} \longrightarrow {}^{1}_{1}\mathrm{H} + {}^{17}_{8}\mathrm{O} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}3) $$

$$ {}^{4}_{2}\mathrm{He} + {}^{9}_{4}\mathrm{Be} \longrightarrow {}^{1}_{0}\mathrm{n} + {}^{12}_{6}\mathrm{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}4) $$

There also exist more complex direct reactions, that energy of the incident particle is transferred directly to a small group of nucleons in the nucleus.

If the energy entered by the arriving particle is gradually distributed among many nucleons of the nucleus, the nuclear states will become growing, however, will be collided different nuclear configurations will exhibit and decay in the resultant system, called "compound nucleus" [25].

A compound nucleus a nuclear reactions processes through the formation may be formed than one way and may decay by more than one mode , that does not depend on the mode of formation , consider the example as:[21].

$$ {}^{4}_{2}He + {}^{10}_{5}B \rightarrow {}^{14}_{7}N^{*} \rightarrow {}^{1}_{0}n + {}^{13}_{7}N \quad \ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}5) $$

Compound nucleus processes typically take much longer (10^{-18} to 10^{-16}) s . This additional time is necessary for the distribution and focus of the accident energy [23].

For the reaction shown in eq.(1-4), (1-5) above, the following quantities are conserved :

Charge: $Z_1 + Z_2 = Z_3 + Z_4$

Mass number: $A_1 + A_2 = A_3 + A_4$

Total energy: $E_l + E_2 = E_3 + E_4$ (the particle kinetic energies plus the energy equivalent of the particle rest masses, $E = mc^2$.)

Linear momentum: $P_I + P_2 = P_3 + P_4$.

Regardless how the compound nucleus is established, it has excitation energy equal to the separation energy of the projectile (α, n, p,…. etc.), it is apparent that the compound nucleus has great excitation energy ,even if the kinetic energy for projectile and the target equal zero [21].

If we ignore nuclear powers and consider only the reactions arising out from coulomb powers, we can speak of four principal types of charged-particle reactions[26].

(1-3-1) Elastic collision with atomic electrons :

In this type the result in a small amount of energy transfer, it is important only at charged particles that are low-energy electrons[26].

That energy transfer was larger than the binding energy at the electron (collision was elastic).

(1-3-2) Inelastic collision with atomic electrons :

In this process ,the coulomb force due to moving particle affects to the atom as a whole[20]. This is the principle of energy transfer, it leads to the excitation of the atom electrons or ionization of the atom, that is the type called (collision),is the controlling process of energy loss, unless the charged particle has a kinetic energy exceeding its rest mass energy, in state the radiation process . In this collision, atomic electron is treated as "free"[26].

(1-3-3) Elastic collisions with a nucleus :

The kind of reactions were known as Rutherford scattering, there is no excitation of the nucleus, or no irradiation[26].The particle loses energy during the rebound of the nucleus.

(1-3-4) Inelastic collision with a nucleus :

Coulomb force interaction at most with the nucleus in this type, if the charged particle has enough energy [20]. This process can leave the nucleus in an excited state [26]. The excited nucleus decay by emitting of (γ –rays) or nucleons [20] .Because heavy particles radiation occurs only at such kinetic energies ($\sim 10^3$ MeV) , if his energy is less than , it is no practical interest remember [26].

(1-4) Interaction of α- particles :

Alpha particles are essentially helium nuclei with 2 protons and 2 neutrons bound together and their mass of (4 amu) [27].This positive charge due to the alpha particles to remove electrons from the orbits of atoms in its neighborhood [28].

Alpha particles are extremely stable particles having a binding energy of about (28.8 MeV) ,the protons and neutrons are together in a very stable configuration by the strong nuclear force [27].

Alpha particles are easily absorbed by materials, and they can travel only a few centimeters in air [28].

Alpha particles generate about (50,000) ion pairs per centimeter of its path, when ionization dry air, giving up around (34 eV) per pair produced and alpha particle dissipates energy (5 MeV) in about (2.5cm) of travel near the end of its track during transmit several energy to neighboring atoms by atomic excitation[29].

The result of their high mass and electrical charge is their shortage to penetrate as deep as other particles [27].

It is produced from certain nuclear reactions and the radioactive decay of heavy nuclides[28].

The average energy for alpha particles emitted from uranium is (4.7 MeV),the range to alpha particles at uranium is (3.2cm) , the average energy at plutonium (5.2 MeV), and the range is (3.7 cm)[30].

By eq. (1- 7), The maximum electron recoil energy and the maximum kinetic energy loss by the incident heavy particle, occurs for($\cos^2 \theta e = 1$) (i.e., for $\theta e = 0$), using M $\gg m_e$,we find that the recoil energy of the electron is:

$$(E_e)_m = 4\frac{m_e}{M_\alpha} E_\alpha \cos^2 \theta e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}6)$$

thus, the maximum energy of the recoil electron is:

$$(E_e)_{max} = 4\frac{m_e}{M_\alpha} E_\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}7)$$

$(E_e)_{max}$: is the recoil energy of the electron , (m_e) : is mass of electron , (M_α) : is mass of alpha-particle, and (E_α) : is the kinetic energy of the incident heavy particle (E_α = 4MeV).

Thus, the electrons, with which an incident alpha particle interacts, can be considered as a "free" electrons at rest [24].

The primary reactions responsible for alpha decay are a balance between the electromagnetic power and nuclear power, alpha decay results of the coulomb repulsion between the alpha particle and the rest of the nucleus, which both have a positive electric charge, but is kept obtain by the nuclear power [23]. Most such alpha-electron interacts result at far less energy loss, although usually enough energy transfer to free the electron from its atom or raise the atom to a high excitation state [24].

The alpha particles can produce neutrons through (α,n) reaction that happen in much nuclear fuel cycle materials as [30]:

$${}^{4}_{2}He + {}^{18}_{8}O \longrightarrow {}^{21}_{10}Ne + {}^{1}_{0}n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}8)$$

$${}^{4}_{2}He + {}^{19}_{9}F \longrightarrow {}^{22}_{11}Na + {}^{1}_{0}n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}9)$$

The energy spectrum of α-emission is discrete (linear) , nuclei of the next radionuclide's decay for α-emission: ${}^{241}_{95}Am$, ${}^{238}_{92}U$, ${}^{230}_{90}Th$, ${}^{227}_{89}Ac$, ${}^{227}_{88}Ra$,${}^{212}_{84}Po$,the operation can be described as follows:[29].

Tow common(α,n) sources in used today are ${}^{241}_{95}Am$ Be, and ${}^{241}_{95}Am$ Li, when the alpha- particle collide at anther nucleus, the probability of a reaction depends on the (Q- $_{value}$) ,threshold energy, and the height of the coulomb barrier, the coulomb barrier is rising enough to make alpha decay away for all but the heavy elements [30].

(1-5) Interaction of Neutrons With Matter :

The neutron is a neutral particle (neutron was discovered by Chadwick in 1932), which is stable only in the confines of the nucleus of the elastic collisions had atom,[31]. Chadwick assumed that emitted and occurred with the hydrogen nuclei in the paraffin and that the emitted radiation was in fact a neutral particle (the neutron) [32].

The neutron is a nuclear particle with a mass rather close to that of the proton ($m_n = 1.675 \times 10^{-27}$kg) (equivalent to (939.6) MeV/c^2 or (1.008667 u), the neutron have mean square radius about (0.8×10^{-15} m) or (0.8Fm), the neutron life-time (T = 886 s) [33].

Neutron is not an elementary particle , in order for the first particle to have a magnetic momentum , it must have an electrical charge and rotation [34]. The neutron has a rotation (1/2 ħ) and because it does not have a net charge [33]. But is composed of three quarks , so the magnetic momentum of these elementary particles meets to give the magnetic momentum neutron and the direction of the neutron's magnetic moment is defined by its spin [34].

These characteristics have to do with the charge and spin of the electron, give rise to electromagnetic forces between neutrons and electrons, these forces , however, are extremely weak [31]. Mass of neutron almost equal hundreds of times mass electron , but almost equal (1/4) the mass of an alpha particle, the source of neutrons is primarily nuclear reactions, such as fission , and also be produced for the decay of radioactive nuclides[28].

Neutrons has force highly penetrating because they had no charge , thus were not repelled by positively charged nuclei [32].The neutron does not exist naturally in free form, but decays into a proton, electron, and anti-neutrino, this radioactive decay, known as beta decay [35].

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu} \quad \text{.......................................(1-10)} $$

The neutron interacts with nuclei via the strong nuclear force and with have magnetic moments ($\mu_n = -1.91$) via the electromagnetic force [33].

Nuclear reactors are the most copious sources of neutrons, these neutrons are usually degraded in energy, having passed through parts of the reactor core, it is convenient to classify neutrons according to their energies[31].

(1-6) Neutron Sources :

Nuclear reactors and accelerators produce neutrons with a enormous range of energies, these are quick sources, and the production of neutrons cat off when they are shut down[32] Much neutron beams may be produce in accelerators by many different reactions, for example, bombardment of beryllium by high-energy deuterons in a cyclotron produces neutrons give to the reaction [35].

$$ {}^{9}_{4}Be + {}^{2}_{1}H \rightarrow ({}^{11}_{5}B)^{*} \rightarrow {}^{10}_{5}B + {}^{1}_{0}n \quad \text{................(1- 11)} $$

Neutron sources also include accelerators, isotopic sources, nuclear reactors , and the most frequently used irradiation facilities are by far, neutrons that can produced by several methods such as:[21].

(1-6-1) Radioactive Elements (Isotopes) :

Radioactivity may be defined as spontaneous phenomenon of emission in unstable atoms that result the formation of new elements (was discovered by Henri Becquerel in 1896) [35]. Nuclear decay occurs with the emission of alpha (α), beta (β), gamma (γ), neutron, proton and even heavy molecules, called elements (isotopes) that are undergo nuclear decay are called radioactive elements isotopes[22]. Neutron sources are based on reactions(α,n),(γ,n), and on spontaneous fission ($^{252}_{98}Cf$), they all produced fast neutrons, it supply neutrons an average at (2.3 MeV) [21].

(1-6-1-1) Radioactive (α,n) Source :

An alpha source, usually radium, polonium , or plutonium and a light metals, such as beryllium or boron , these can be mixed together as powders and encapsulated to make a "radioactive" neutron low intensity source, neutrons are emitted result of (α, n) reactions following eq.[31].

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{1}_{0}n + ^{12}_{6}C \quad (Q = 5.70\ Mev) \ldots\ldots\ldots\ldots (1\text{-}12)$$

$$^{4}_{2}He + ^{10}_{5}B \rightarrow ^{1}_{0}n + ^{13}_{7}N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1\text{-}13)$$

The reaction alpha with beryllium is the more advantageous yield of neutrons , although neutron sources may be prepared by mixing an alpha emitter with boron , as in table (1-1) [36].

Alpha particles move in slow motion by different amounts of what before striking a nucleus, and the neutron and the recoil nucleus share a total energy equal to the sum of the (Q value), neutrons leave the source with a continuous energy spectrum, that is dependent upon the energy of the alpha particle, the energy spectrum of a neutron can be divided down into four main regions: thermal, intermediate, fast, and relativistic [31].

Some common (α , n) sources are shown in table (1-1), $^{239}_{94}Pu - ^{9}_{4}Be$ and $^{210}_{84}Po - ^{9}_{4}Be$ sources produce neutrons only by the (α , n) reaction, eq.(1-14).

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

$$^{4}_{2}He + ^{7}_{3}Li \rightarrow ^{1}_{0}n + ^{10}_{5}B \quad \text{.........................(1- 14)}$$

Will take place in a $^{226}_{88}Ra - ^{9}_{4}Be$ source, since ($^{226}_{88}Ra$) decays by (4.78 MeV) α-emission, and to short-lived daughters nucleus , light elements are used in these sources in order to reduce coulomb repulsion between the alpha particle and the nucleus , however the short half-life of $^{210}_{84}Po$ (138 d) requires frequent recalibration of the source [36].

More common source such as ($^{241}_{95}Am$ - $^{9}_{5}Be$) , as in table (1-1)[37].

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

$$^{4}_{2}He + ^{19}_{9}F \rightarrow ^{1}_{0}n + ^{22}_{11}Na \quad \text{......................... .(1- 15)}$$

(1-6-1-2) Photoneutron Source :

The sources of photons include radioisotopes , nuclear reactions, and bremsstrahlung radiation [21] . Can be obtained photoneutron sources, monoenergetic by selecting a nuclide that emits a gamma ray of a single energy , photoneutron sources of (γ, n) reactions decay in intensity with the half-life of the photon emitter [31].

If the photon energy is greater than the nuclear binding energy of the most loosely bound neutron ,the approximate energy of the ejected neutron is given by:

$$E\gamma \approx \frac{A-1}{A}\left(E\gamma - Q - \frac{E_{\gamma}^{2}}{2m_{n}c^{2}(A-1)} + \frac{E_{\gamma}}{A}\sqrt{\frac{2(A-1)}{(m_{n}c^{2}A)(E_{\gamma}-Q)}}\cos\theta\right) \text{......(1-16)}$$

where : *A* = is the mass of the target nucleus, Eγ = is the energy of the photon, E γ = is the energy of the neutron, Q= is Q-value ,
m_n = is the neutron mass, *c* = is the velocity of light, and θ = is the angle between photon and neutron flight direction.

Photoneutron sources in experiments consist of a highly active gamma source, originating from decay in radionuclides, surrounded by a target material such as beryllium or heavy water[38].

All photoneutron sources have gamma-ray backgrounds of >1000 photons per neutron, and be monoenergetic except the last, $^{226}_{88}Ra$ emits gamma rays of several energies , as in table (1-2) [31].

Beryllium is used because its stable isotope $^{9}_{4}Be$ has a weakly connected last neutron with a binding energy of only (1.63) MeV, can cause neutrons ejected by the (γ,n) reaction , as show in eq. (1-17) , (1-18) below[28].

But the deuterium nucleus , consisting of only a proton and a neutron , is a widely studied system in the field of atomic physics , in general , the photo disintegration reaction of a nuclide (X) with atomic number A and charge number Z is the inverse of a neutron absorption reaction [38].

$$^{A}_{Z}X + \gamma \longrightarrow {}^{A-1}_{Z}X + {}^{1}_{0}n$$

$$^{9}_{4}Be + \gamma \longrightarrow [^{9}_{4}Be^{*}] \longrightarrow {}^{8}_{4}Be + {}^{1}_{0}n \ (Q= -1.63 \text{ MeV}) \ldots\ldots\ldots(1\text{-}17)$$

$$^{2}_{1}H + \gamma \longrightarrow [^{2}_{1}H^{*}] \longrightarrow {}^{1}_{1}H + {}^{1}_{0}n \quad (Q=-2.226 \text{ MeV}) \ldots\ldots(1\text{-}18)$$

Sources made from $^{226}_{88}Ra$ and $^{124}_{51}Sb$ have a very high gamma level relative to neutron productivity, as in [37].

$$^{124}_{51}Sb + {}^{1}_{1}P \longrightarrow {}^{125}_{52}Te + \gamma + 1.7 \text{ MeV followed by}$$

$$^{2}_{1}H + \gamma \longrightarrow [^{2}_{1}H]^{*} \longrightarrow {}^{1}_{1}H + {}^{1}_{0}n \text{ (few MeV)} \ldots\ldots\ldots\ldots\ldots(1\text{-}19)$$

Table (1-1) Isotopic neutron sources :

Source	Average neutron energy (MeV)[32]	Half-life $t_{1/2}\,y$ [31]	Yield $(\frac{n}{s\,.\,gm})$ [21]
${}^{210}_{84}Po - {}^{9}_{4}Be$ (α,n)	4	0.378 y	1.0×10^{10}
${}^{226}_{88}Ra -$ Be (α,n)	5	1.622 y	7×10^{5}
${}^{239}_{94}Pu -$ Be (α,n)	4.5	24.36y	1.0×10^{5}
${}^{241}_{95}Am - Be$ (α,n)	4.5	462 y	7×10^{6}
${}^{242}_{96}Cm\,{}^{241}_{95}Am - Be$ (α,n)	4	0.446 y	1.0×10^{10}
${}^{124}_{51}Sb - Be$ (γ,n)	0.024	0.164 y	1.0×10^{10}

(1-6-2) Spontaneous Fission Sources :

Fission in heavy nuclei can occur spontaneously or by bombardment with energetic particles, the probability of spontaneous fission is low and increases with mass number of the heavy nuclei ,noted that spontaneous fission is an alternative to alpha decay or emission (γ-rays)[39]. And they can be encapsulated and used neutron sources such as ${}^{254}Cf$, ${}^{244}Cm$, ${}^{242}Cm$, ${}^{238}Pu$, and ${}^{238}U$, in most cases the half-life for spontaneous fission is much greater than that for alpha decay, as in table (1-2) [31].

There are no naturally radioactive isotopes of neutrons but finally an industrial (${}^{254}Cf$) is produced, and the neutrons are emitted with a spectrum of energies about(2.3 MeV),such as in reaction [15].

$$ {}^{252}_{98}Cf \rightarrow {}^{251}_{98}Cf + {}^{1}_{0}n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}20) $$

The cross section for neutron induced fission is much higher for thermal neutrons (100) MeV than for the fast neutrons (1–2)MeV that are produced [40].

Table (1-2) Spontaneous Fission Sources [24]:

Source	Half-life $t_{1/2}$ y	Fission prob. Per alpha decay (%)	Yield ($\frac{n}{s \cdot gm}$)
$^{233}_{92}U$	1.59×10^{5} y	1.3×10^{-10}	$8.6 \times \mathbf{10^{-4}}$
$^{237}_{93}Np$	2.14×10^{6} y	2.1×10^{-12}	$\mathbf{1.1 \times 10^{-4}}$
$^{240}_{94}Pu$	6569 y	5.0×10^{-6}	**920**
$^{241}_{95}Am$	433.6 y	4.1×10^{-10}	1.18
$^{249}_{98}Cf$	350.6 y	5.2×10^{-7}	$2.5 \times \mathbf{10^{3}}$
$^{252}_{98}Cf$	2.638 y	3.09	$2.3 \times \mathbf{10^{12}}$
$^{254}_{98}Cf$	60.5 y	99.69	1.2×10^{15}
$\mathbf{^{250}_{96}Cm}$	6900 y	61.0	$1.6 \times \mathbf{10^{10}}$

(1-6-3) Nuclear Accelerator :

Accelerator is a machine used to produce, high-energy, high-speed beams of charged particles, such as electrons, protons, or heavy ions, for research in high-energy and nuclear physics, synchrotron radiation research, medical therapies, and some industrial applications [40].

There are two basic categories of accelerators, first is a Electrostatic accelerators: (static electric fields are used to accelerate particles, kinetic energy for particles in these devices is limited by electrical breakdown), such as, the Cockcroft-Walton generator and the Van de Graff generator[41].

The second is oscillating field accelerators:(The accelerator that uses electromagnetic fields at specific radio frequencies to propel charged particles to the speed of light),such as, Linear Accelerators (LINAC), ,Synchrotron, Betatron, and the cyclotron, LHC, RHIC, Tevatron, the interaction depends on them on the particle charge and velocity and on the field, and used in a large variety of applications [42].

Accelerators produce fast neutrons as products of charged-particle by (D-T) reactions, the most common device is the so-called neutron generator, the maximum neutron flux provided by a neutron generator is of the order of 10^{12} n /(cm^2.s) ,which practice on the reaction[21].

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{1}_{0}n + ^{4}_{2}He + 17.586 \text{ MeV} \quad \ldots\ldots\ldots\ldots (1\text{-}21)$$

This reaction is a direct source of high- energy neutrons and is accelerated to about (200 keV), the reaction is exoergic and discharges (17.6 MeV), of which (14.1MeV) are given to neutrons monoenergetic produced [32].

Also can be produce fist neutrons with an average energy of about (2.5 MeV) by the (d , d) reaction, neutron flux of 10^9 n /(cm^2.s) , which practice on the reaction [21].

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{1}_{0}n + ^{3}_{2}H + 3.266 \text{ MeV} \ldots\ldots\ldots\ldots (1\text{-}22)$$

It can be used radiation from accelerated particles produce beams of secondary particles are in turn used to study materials and their properties, such as :

– Photons production (x-rays, gamma-rays, visible light).

– Neutrons production from beams of protons [40].

(1-7) Classification of Neutrons :

In a nuclear reaction, neutrons can be classified according to their kinetic energies as shown in the table (1-3).

Table(1-3) Classification of neutrons [32].

	Classification of Neutrons	**Energy of neutron**
1	Cold neutrons	0.0002 eV .
2	Thermal neutrons	$0.0002 < E_n < 0.1$ eV
3	Epithermal neutrons	~ 0.5 eV
4	Resonance neutrons	1 - 100 eV
5	Slow neutrons	100 - 1000 eV
6	Intermediate neutrons	1 keV - 0.5 MeV
7	Fast neutrons	0.5 - 10 MeV
8	High energy neutrons	10-200 MeV
9	Very high energy neutrons	> 200 MeV

(1-8) Neutron Reactions Classification :

The reactions of neutrons with nuclei are divided into two categories: scattering and absorption[21].There are various neutron reactions, as shown in fig.(1-1)[26]:

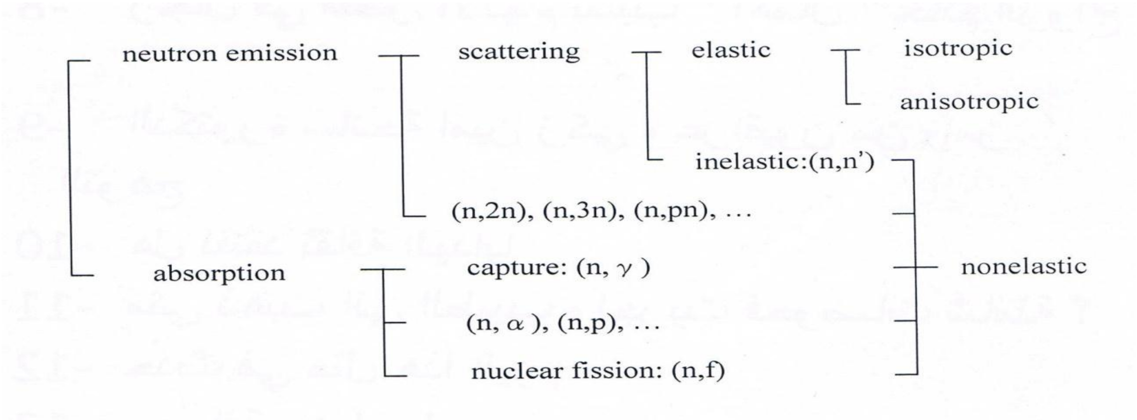


Fig.(1-6) Neutron reactions[43].

The types and rates of neutron reactions depend onto the nucleus which to collision and neutron energy, most reactions become threshold reactions, for many nucleus, and they occur when the neutron energy is more than about (1MeV)[43].

(1-8-1) Scattering Reaction:

In this cause, the neutron interacts with a nucleus, but both particles appear again after the interaction as: [21].

$${}^{1}_{0}\mathrm{n} + {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z}\mathrm{X} + {}^{1}_{0}\mathrm{n}$$

Neutron scattering interaction occurs when a neutron hits the nucleus , emits a single neutron [28]. Neutrons may collide together with nuclei and undergo either elastic or inelastic scattering [35].

(1-8-1-1) Elastic scattering reaction X (n, n)X :

This interaction occurs between a neutron and a target nucleus , there is no energy transferred into nucleus excitation, where momentum and kinetic energy are conserved[28].

Or the nucleus reaches the state of excitement by kinetic energy , after the collision, excited nucleus will return at the ground state through emitting one or more (γ- rays) [21].

It can be shown the energy $\mathbf{E_n}$ (scattering nucleus), as:[35].

$$E_n = E_i \left\{\frac{M-m}{M+m}\right\}^2 \quad \text{.... ....(1-23)}$$

We have the energy transferred for the target nucleus is $E_f = E_i - E_n$

$$E_f = E_i \left[1 - \left(\frac{M-m}{M+m}\right)^2\right] \quad \text{..............................(1-24)}$$

where : E_i = energy of the incident neutron, E_n = energy of the scattering neutron after a head-on collision , m = mass of the incident neutron, M = mass of the scattering nucleus [35].

Transferred a part of kinetic energy of the neutron to a nucleus , at elastic scattering the recoil energy of the nucleus is given by (E_R)[22].

$$E_R = E_n \frac{4A}{(1+A)^2} \cos^2\theta \quad \text{..............................(1-25)}$$

where : E_R= is the recoil energy nucleus , E_n= is the kinetic energy of the neutron, A = is the mass number of the nucleus,

θ = is the scattering angle (In the case of head-on collision, θ =0°)[22].

An example of this interaction is a “billiard-ball” type collision, in which kinetic energy and momentum are conserved, by applying these conservation laws[35].

(1-8-1-2) Inelastic scattering reaction X (n, $\grave{n}$) X :

In this case, kinetic energy is transferred to the target nucleus and the excitation energy there is emitted as a gamma-ray (photon) (γ-rays play an significant part in the shielding of high energy neutron)[35].

Sum of the kinetic energy of the neutron outward , the target nucleus ,and the total gamma energy emitted is equal to the initial kinetic energy of the accident neutron[28].In this process, kinetic energy is not conserved, but total energy is conserved[22].

It is expected that the threshold energy should be partially greater than the excitation energy, the minimum possible value of the threshold energy (E_1) for which the reaction can take place , (If we take θ = 0), we find [26].

$$E_{th} = E^{*} \left[\frac{M + m_n}{M}\right] \qquad \text{.....................................(1- 26)}$$

where: E_{th} = is the threshold energy , M = is the target mass ,

E^{*}= is the excitation energy , m_n = is the neutron mass .

Inelastic scattering and next secondary (γ-rays) play an important role in the shielding on high energy neutrons, but are undesirable complication at detection of fast neutrons based of elastic scattering[22].

(1-8-2) Absorption :

Most absorption reactions come in the loss of a neutron, coupled for the production of a charged particle or gamma ray, the absorption reactions were classified , into neutron capture, particle ejection, and fission [27].

(1-8-2-1) Absorption Reaction X (n, x)Y :

In this kind, the neutron disappears, however one or more other particles appear after the interaction takes place. Where (**x)** is may be (p, d, t, α , 2n ,3n or fission) , for example:[30].

$$ {}_{0}^{1}n + {}_{Z}^{A}\mathrm{X} \longrightarrow {}_{Z-2}^{A-3}\mathrm{Y} + {}_{2}^{4}\mathrm{He} $$

(1-8-2-2) Neutron capture $\mathbf{X^{A}(n,\gamma)\,X^{A+1}}$:

In radioactive capture, the accident neutron enter the target nucleus , and figuration a compound nucleus[27]. Usually leaves the compound nucleus in a highly excited state , the excited nucleus decays quickly (around10^{-13} s) by emit one or more capture gamma rays.

$$ \mathrm{n} + \mathrm{X}^{A} \longrightarrow [\,\mathrm{X}^{A+1\,*}] \longrightarrow \mathrm{X}^{A+1} + \gamma $$

$$ {}_{0}^{1}\mathrm{n} + {}_{92}^{238}\mathrm{U} \longrightarrow [\,{}_{92}^{239}\mathrm{U}^{*}] \longrightarrow {}_{92}^{239}\mathrm{Np} + {}_{0}^{0}\gamma \;\ldots\ldots\ldots\ldots\ldots(1\text{-}27) $$

The boron whose natural isotope has a large propensity to absorb neutrons, with kinetic energies less than (1eV) shown as by eq.(1-28) .

$$ {}_{5}^{10}\mathrm{B} + {}_{0}^{1}\mathrm{n} \longrightarrow [{}_{5}^{11}\mathrm{B}^{*}] \longrightarrow {}_{3}^{7}\mathrm{Li} + \alpha + \gamma \;\ldots\ldots\ldots\ldots\ldots\ldots(1\text{-}28) $$

(1-8-2-3) Fission Reaction (n, f) :

One of the extreme important reactions this neutrons can cause is fission[10]. Some very heavy nuclides actually undergo radioactive decay by spontaneously fissioning into two lighter nuclides .For example, ^{252}Cf has a half-life of (2.638 y) and usually decays by alpha particle emission .

Nuclides that fission only when struck with a neutron with kinetic energy a bout (1 MeV or more) , such as ^{238}U and ^{240}Pu, are said to be fissionable, i.e., they undergo fast fission, the fission interaction may be written in another way by eq.(1- 29) .

$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \xrightarrow[24m]{\beta^-} ^{239}_{93}Np \xrightarrow[56h]{\beta^-} ^{239}_{94}Pu$ ....(1-29)

Compound nucleus is produced in a very excited state, with a lifetime of about 10^{-14} s .

$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{236}_{92}U^* \longrightarrow Y_H^{+n} + Y_L^{+m} + (n + m)\, e^-$.....…….......(1-30)

where: the Y_H and Y_L indicated respectively, to the heavy and light primary fission products, and the ionic charge (n) and (m) on the fission fragments is about (20) [24].

(1 -9) Neutron cross section :

Consider a mono energetic neutrons parallel beam incident on target thickness **t,** the microscopic cross- section (barn) shows as:

$$\sigma = R / I \quad ....(1\text{-}31)$$

where:

σ = The microscopic cross section (barn $=10^{-24} cm^2 = 10^{-28} m^2 = 10^2 fm^2$)

since the nuclear radius is approximately(10^{-15}- 10^{-14}) m,

(1b) is approximately equal to the cross-sectional area of a nucleus.

R= The number of reactions (events) per unit time per nucleus,

but $R = I\ N\ t\,\sigma$, unit of (reaction / s), I = The number of incident particles per unit time per unit area (n/m^2s) [21].

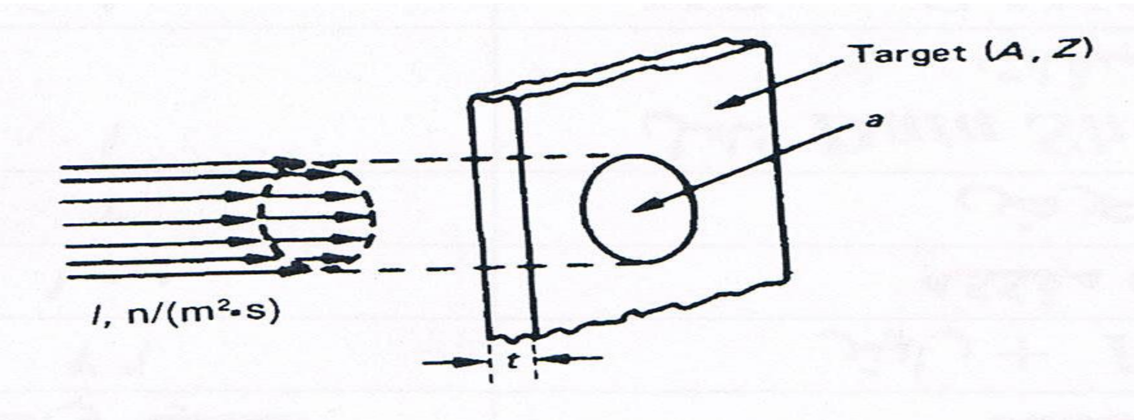


Fig.(1-7) A parallel neutron beam hitting a thin target: a = area of target struck by the beam [21].

The probability of a neutron interacting with a nucleus for a particular reaction is dependent upon not only the kind of nucleus involved but also the energy of the neutron[27].For consistent comparison and use, the cross section is often cited at 0.0253eV, corresponding to neutron speed 2200 m/s [42]. Accordingly, the absorption from a thermal neutron in most materials is much more probable than the absorption from a fast neutron[27].

The probability of a particular reaction occurring between a neutron and a nucleus is called the microscopic cross section (σ) of the nucleus for the particular reaction[42].

This cross section will vary with the energy of the neutron, the microscopic cross sections may also be regarded as the effective area the nucleus presents to the neutron for the particular reaction .

The larger the effective area ,the greater the probability for reaction, therefore, it is necessary to define another kind of cross sections have as the macroscopic cross sections (Σ) .

The macroscopic cross section is the probability of a given reaction occurring per unit travel of the neutron as shown below .

$$\Sigma = N\sigma \quad \text{..(1-32)}$$

where: Σ = macroscopic cross sections (cm^{-1}),(m^{-1})

N = atom density of material (atoms/cm^3) = ($1/_{cm^3}$)

σ = microscopic cross-sections (cm^2/atom) ,(m^2/atom)

Or (the sum of the microscopic cross-sections of the individual nuclei in the target per unit volume is designated as the macroscopic cross section) and is given by:[21].

$$\sum = N_1\sigma_1 + N_2\sigma_2 + \ldots + N_n\sigma_n \ (cm^{-1})$$

A neutron interacts for an atom of the substance it enters in two ways, the probability of a neutron existence absorbed by a particular atom is the microscopic cross sections for absorption, $\boldsymbol{\sigma_a}$,(absorption cross-sections increases as the velocity (kinetic energy) of the neutron decreases) [28].

$$\sigma_a = \sigma_f + \sigma_c \quad \ldots\ldots(1\text{-}33)$$

The probability of a neutron scattering of a particular nucleus is the microscopic cross sections for scattering, $\boldsymbol{\sigma_s}$ [28].

$$\sigma_s = \sigma_{se} + \sigma_{si} \quad \ldots\ldots(1\text{-}34)$$

Where neutron cross sections are defined separately for each type of reaction and isotope .

σ_s = scattering cross sections,

σ_{se}= elastic scattering cross sections,

σ_{si}= inelastic scattering cross sections,

σ_a = absorption cross sections,

σ_c = capture cross sections,

σ_f = fission cross sections[21] .

Sum of the microscopic cross sections at absorption and the microscopic cross sections at scattering are the total microscopic cross section, $\boldsymbol{\sigma_T}$ [28].

$$\sigma_T = \sigma_a + \sigma_s \quad \ldots\ldots(1\text{-}35)$$

(1-10) Cross section of (α,n) reactions :

The problems of nuclear technology are many; one of them is the development of analytical methods for the control and protection from nuclear fuel radiation , another is the production of neutron and isotopic energy sources based on alpha emitting radio nuclides. This latter application requires the knowledge of the yield of neutrons resulting from the absorption of alpha particles by nuclei of elements [44].

The nuclear data on (α,n) reactions play an important role in the field of radiation shielding and criticality safety relating to storage, transport and handling of spent fuel [45].

(1-11) Previous works :

The experimental and theoretical cross sections of (α,n) reactions for rare earth elements have been extensively studied the most important are :

(1-11-1) Cross section $^{139}_{57}\mathrm{La}\,(\alpha,n)\,^{142}_{59}\mathrm{Pr}$ reaction:

1- Verdieck, and Miller (1967).The cross sections of this reaction was measured for alpha energy (10.1 to 39.6) MeV[46].

(1-11-2) Cross section $^{141}_{59}\mathrm{Pr}\,(\alpha,n)\,^{144}_{61}\mathrm{Pm}$ reaction:

1- Ansari, and Sathik (2005). The cross sections of this reaction was measured for alpha energy (15.71 to 44.57) MeV [47].

2- Sauerwein,and…et al. (2011). The cross sections of this reaction was measured for alpha energy (11.305 to 14.426) MeV [48].

(1-11-3) Cross section $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ reaction:

1- Denzler, and….et al (1995). The cross sections of this reaction was measured for alpha energy (13.3 to 25.4) MeV [49].

(1-11-4) Cross section $^{159}_{65}Tb(\alpha,n)^{162}_{67}Ho$ reaction:

1- Singh ,and Gadkari.(2001)The cross sections of this reaction was measured for alpha energy (15.5 to 46.4) MeV [50].

(1-11-5) Cross section $^{165}_{67}Ho(\alpha,n)^{168}_{69}Tm$ reaction:

1- Wilkinson, and Hicks. (1949).The cross sections of this reaction was measured for alpha energy (19.0 to 38.0) MeV [51].

2- Pilger , and Martin (1966).The cross sections of this reaction was measured for alpha energy (15.9 to 40.1) MeV [52].

3- Chery, and Demeyer.(1968). The cross sections of this reaction was measured for alpha energy (17.35 to 36.10) MeV[53].

4- Mukherjee and et al.(1 991).The cross sections of this reaction was measured for alpha energy (16.8 to 66.7) MeV [54].

5- Singh, and Agarrwal.(1992).The cross sections of this reaction was measured for alpha energy (14.84 to 47.18) MeV[55].

6- Singh , and Prasad. (1995). The cross sections of this reaction was measured for alpha energy (15.8 to 33.9) MeV [56].

7- M.S.Gadkaet and et al. (1997).The cross sections of this reaction was measured for alpha energy (20.0 to 65.8) MeV [57].

8- Tarkanyi ,and ….et al. (2010). The cross sections of this reaction was measured for alpha energy (12.0 to 38.8) MeV[58].

9- Glorius,and … et al. (2014). The cross sections of this reaction was measured for alpha energy (10.9389 to 15.3022) MeV[59].

(1-11-6) Cross section $^{169}_{69}\mathrm{Tm}(\alpha,n)\ ^{172}_{71}\mathrm{Lu}$ reaction:

1- Singh,and……..et al (1990). The cross sections of this reaction was measured for alpha energy (16.4 to 46.8) MeV[60].

2- Mukherjee,and…et al (1992). The cross sections of this reaction was measured for alpha energy (33.68 to 70.55) MeV [61].

3- Mohan, and Rao. (1994). The cross sections of this reaction was measured for alpha energy (15.9 to 56.5) MeV[62].

4- Patel, and Shah. (1999). The cross sections of this reaction was measured for alpha energy (20.0 to 65.7)MeV[63].

5- Kiss,and … .et al (2011). The cross sections of this reaction was measured for alpha energy (11.0000 to 17.4843) MeV[64].

6- Rauscher, and .et al.(2012).The cross sections of this reaction was measured for alpha energy (12.5707 to 15.9801) MeV [65].

(1-12) The aim of the present work :

1- Study the nuclear properties of (α,n) reactions to know which nuclear reaction has good properties from other studied nuclear reaction, to make it important in many nuclear applications, which including in the production of fiber optical laser, after doped optical fiber glass with rare earth elements (REEs).

2- Study of possible nuclear reaction $(\alpha\,,n)$ and (n,α) extraction of neutron yield needed to produce isotopes used in nuclear, engineering, medical and military fields and in various scientific researches.

3- Obtaining the semi empirical formula for the ground state to calculate the cross sections in order to produce some element by inverse reaction technique.

We have tried to formulate parametric expressions for cross sections using fitting type , and using computer program. The cross sections of the mentioned reactions were reproduced in fine steps of energy for the incident projectile on thin targets with elements that have an atomic number (Z = **57, 59, 62, 65, 67, and 69**) using the most recent data available in the libraries .

4- Calculating the Q_0-value, threshold energy, coulomb barrier, stopping power and neutron yield and abounds the probability of occurrence of their reactions . As well as the present work was covered the energy range which the other authors data didn't cover it, that is indicated the present measurements necessarily involves apply to the ground state .

5- Determining the neutron yield using the modified cross sections and the stopping power of the above reactions are compared with those published in the libraries.

Chapter Two

Theory

Chapter Tow

(2-1)Kinematics of Nuclear Reactions:

Consider the x(a,b) y reaction, neglecting electron binding energy , a particle of mass m_a, having speed v_1, (kinetic energy E_1) hitting a stationary particle of Mass M_x [4]. The particles M_b, M_y are produced as a result of this reaction with speeds V_b , V_y (kinetic energies E_b, E_y), as shown in fig.(2-1)[21]. You must balance the energy in interaction :

$$M_a c^2 + E_a + M_x c^2 = M_Y c^2 + E_y + M_b c^2 + E_b \ldots\ldots (2\text{-}1)$$

$Q_{\text{-value}}$ of the interaction is modified as the variation in block energy of the reactants and product [66].

$$Q_{\text{-value}} = [(M_a + M_x) - (M_b + M_y)] c^2 \ldots\ldots\ldots\ldots (2\text{-}2)$$

$$= E_b + E_y - E_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2\text{-}3)$$

Is called the $Q_{\text{-value}}$ of the reaction. If $Q_{\text{-value}} > 0$, the interaction is called (exothermal) , If $Q_{\text{-value}} < 0$, the reaction is called endothermic or (endoergic)[4].Also can be account using mass excess, Δ, as :

$$Q = \Delta(\text{ projectile }) + \Delta(\text{target }) - \sum \Delta(\text{products}) \ldots\ldots (2\text{-}4)$$

The interaction in the laboratory, can be using conservation from momentum , in order to only the angle θ and E_b of b with estimate to the directing of motion of a sufficient to limit $Q_{\text{-value}}$.

Momentum, X axis:

$$M_a V_a = M_b V_b \cos\theta + M_y V_y \cos\emptyset \quad \ldots\ldots\ldots\ldots\ldots\ldots (2\text{-}5)$$

Momentum, Y axis:

$$M_b V_b \sin\theta = M_y V_y \sin\emptyset \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2\text{-}6)$$

P (Momentum) = MV = $(2ME)^{1/2}$, can substitution on as eq.(2-6).

$$(M_a E_a)^{1/2} - (M_b E_b)^{1/2} \cos\theta = (M_y E_y)^{1/2} \cos\emptyset \quad \ldots (2\text{-}7)$$

$$(M_b E_b)^{1/2} \sin\theta = (M_y E_y)^{1/2} \sin\emptyset \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}8)$$

Quarter and collect the equations, we get:

$$M_a E_a - 2\,(M_a E_a M_b E_b)^{1/2} \cos\theta + M_b E_b = M_y E_y \quad .\ldots\ldots\ldots(2\text{-}9)$$

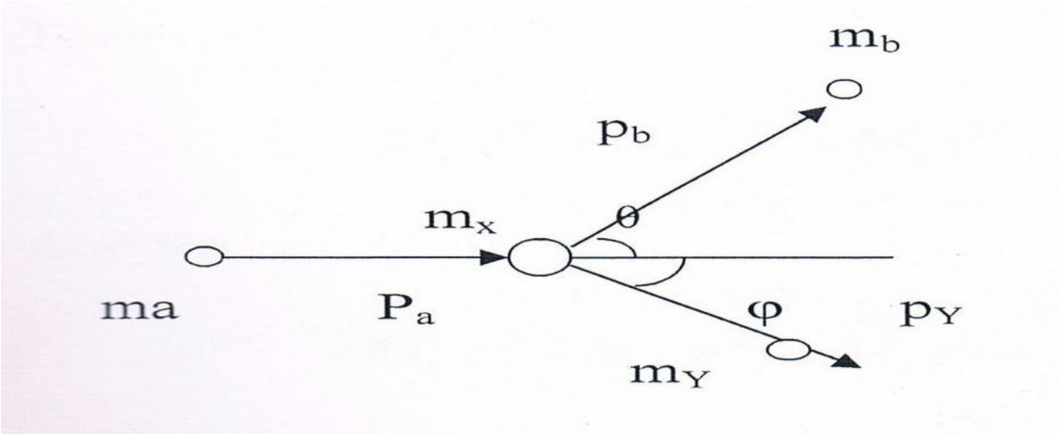


Fig.(2-1) The kinematics of the reaction x(a, b)y, in laboratory system[67].

Before we own mentioned : $Q_{\text{-value}} = E_x - E_a - E_y$

Plugging in this definition of $Q_{\text{-value}}$ the value of E_Y, we have just recalculated, we have :

$$Q_{\text{-value}} = E_b \left(1+ \frac{M_b}{My}\right) - E_a\left(1- \frac{M_a}{M_y}\right) - \frac{2}{m_y} (M_a E_a M_b E_b)^{1/2} \cos\theta$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}10)$$

We can using this eq.(2-11) the calculate the energy of the particle emitted.

$$E_X{}^{1/2} = \frac{(M_a M_b E_a)^{1/2} \cos\theta \pm \{M_a M E_a \cos^2\theta + (M_y + M)[M_y Q + (M_y - M_a) E_a]\}^{1/2}}{M_Y + M_b}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}11)$$

Where: E_{lab}= is the kinetic energy at the labs, order before the interaction .

$$E_{\,lab} = \frac{1}{2} M_a v_a^2 \quad \text{.................................(2-12)}$$

Look the same interaction as substantive in the center–of mass in fig.(2-2) , total momentum of the particles is zero [68]. in the center–of mass ,the kinetic energy is .

$$E_{\,CM} = \frac{(M_a + M_x)V_{CM}^2}{2} \quad \text{........................(2-13)}$$

Where : $V_{CM}\left[\frac{V_a M_a}{(M_a + M_x)}\right]$ is the speed of the (CM) . Substituting , in the above equations, we have .

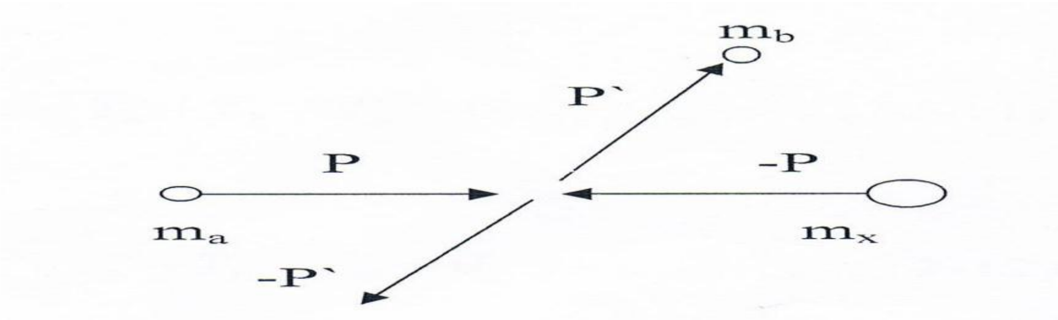


Fig.(2-2) The kinematics of the reaction x(a, b)y, in center of Mass(CM) coordinated [67].

$$E_{CM} = \frac{1}{2}(M_a + M_x)\left[\frac{M_a V_a}{M_a + M_x}\right]^2 = \frac{1}{2} M_a V_a^2 \left(\frac{M}{M_a + M_x}\right)$$

$$E_{\,CM} = E_{\,lab}\left(\frac{M_a}{M_a + M_{\,x}}\right) \quad \text{........................(2-14)}$$

Previously we had said that:

$E_{\,lab} = \frac{1}{2} M_a v_a^2$, where is the kinetic energy of the projectile , is not the hard be dissipated in the interaction [66].

Instead of that , an amount(E_{CM}), must be load out of the way by the (CM), the case for own the interaction happened is that [68].

$$E_p \geq -Q_{\text{-value}} \frac{(M_a + M_x)}{M_x} \quad \text{.........................(2-15)}$$

The probability of interaction between the alpha particle, when reach at another nucleus, depends at the threshold energy of ,the height of the Coulomb barrier and the $Q_{\text{-value}}$ [66].

A positive $Q_{\text{-value}}$ means that the interaction gives emission of energy , A negative $Q_{\text{-value}}$ means that the alpha particle should own at low that a lot energy in the (CM) reference setting before proceed the interaction, it is called of threshold energy if this minimum energy request is transformed to the laboratory reference setting [30].

$$(E_{th}) = -\left(1 + \frac{4}{A}\right) Q_{\text{-value}} \quad \text{..............................(2-16)}$$

(if, $Q_{\text{-value}}$ is negative (Exoergic), either $Q_{\text{-value}}$ is positive (Endoergic)

Or anther the threshold energy for interaction is :[21].

$$E_{th} = |Q| \frac{M_1 + M_2}{M2} \quad \text{..................................(2-17)}$$

Must alpha particle overcome of coulomb barrier (is the strength of the electrostatic repulsion) to enter the target nucleus and interact :

$$\text{Where is coulomb barrier (MeV)} = \frac{Z_1 Z_2 e^2}{r_0(A_1^{1/3} + A_2^{1/3})} \quad \text{............(2-18)}$$

It must be : $Z_1 = 2$, $A_l = 4$, $e^2 = 1.44$ M eV. fm, $r_0 = 1.2$ fm, and Z_2 and A_2 must refer to nucleus of the target [30].

(2-2) Atomic Mass, Mass excess, packing fraction:

It is ordinarily expressed in unified atomic mass units (u) or (amu), (1(amu) is energy unit in terms of mass) defined as $1/12$ of the mass of a single $^{12}_{6}C$ atom (at rest), the atomic mass means it the matter of particle an atomic, molecule or subatomic particle, (1u = $\frac{1}{2}$ m $^{12}_{6}C$ = 931.481 MeV/c^2 = 1.66043x10^{-27}Kg) [69] .

The matter of the atom is least than the sum of the masses of nucleons and electrons that comprise a nucleus of the atom mass, is given by :

$$M(N,Z) = Z\, M_P + (A\,,Z)\, M_N - B_e\,(A\,,Z) \quad \ldots\ldots\ldots(2\text{-}19)$$

Where : M_P, M_N =are masses of hydrogen atom, neutron respectively, B_e (A , Z) = for a nuclide with atomic number Z and neutron number N. (The binding energy can be expressed as M(A , Z) = B_e (A , Z) c^2 .

The mass excess can be converted to energy , energy equivalent of (1 amu) is obtained using , $E = mc^2$, where :

E=1.66053886 x 10^{-27} x (2.99792458 x $10^8)^2$ = 1.4924179 x 10^{-10} Joule. But The energy units used are (eV, keV ,MeV),

1 amu = $\frac{1.4924 \times 10^{-10}}{1.6021 \times 10^{-19}}$ eV = 931.5 MeV , energy is expressed in either amu or MeV.

Since binding energy is in (MeV) , masses also have to be expressed (MeV) , expression similar to the mass defect is the mass excess, known as the variation .

$$\text{Mass excess} = (M - A) = \text{Excess energy} / c^2 \quad \ldots\ldots\ldots(2\text{-}20)$$

M : where it the actual mass of the nucleus (amu),

A : is the number of mass.

The different nuclei have different mass defects, accordingly energy is emitted or absorbed through a nuclear interaction [43].

Packing fraction is known as a way to express the different of isotopic mass from hole mass number (atomic mass). Is given by.

$$\text{Packing fraction} = \frac{M-A}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}21)$$

The value of packing fraction depends upon the manner of packing of the nucleons with in the nucleus.

Reduced mass(μ) is calculated from the following equation as :

$$\mu = \frac{(M_a M_x)}{(M_a + M_x)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}22)$$

(M_a) where is the mass projectile atomic,

($M_{x)}$ is the atomic mass of the target [22].

(2- 3)Binding Energy :

Binding energy B(N,Z) of the nucleus are equal to the mass transformed into energy when the (Z) protons and the N =A - Z neutrons got together and formed the nucleus. Energy amount equal to the binding energy was come up when the nucleus was created, or the binding energy B(A, Z) is equal to the energy necessary to break the Nucleus apart into its constituents, Z free protons and (N) free neutrons.

Discussing of concept the binding energy is useful to calculation released energy or absorbed in nuclear reactions and the calculation of nuclear masses [21].

Binding energy of the nucleus is given by the following eq.(2-23), and know same equation also the mass of nucleus [21].

$$BE(A, Z) = [Z\,M_P + N\,M_n - M\,(A\,,Z)]\,c^2 \text{ ....(2-23)}$$

The real block from an atomic nucleus is not the total of the masses of the protons(M_P) and the masses(M_n) of (A –Z) neutrons of whose it formed , and stable nuclides gets a defect in mass[70].

$$\Delta M = [ZM_P] + (A - Z)M_n\,] - {}^{A}_{Z}M \quad \text{.....................(2-24)}$$

Conceptually it is believed that this mass defect (ΔM) at the time that was formed the nucleus having been converted to energy ($E = \Delta Mc^2$) , raise the nucleus into a negative energy state .Average binding per nucleon is given by:

$$B_{averge} = \frac{B(A\,,Z)}{A} \quad \text{..............................(2-25)}$$

Is plotted as a function of A, one obtains the result shown in figs.,(2-3) and (2-4). The average binding energy changes relatively little, especially for A > 30. Notice that fig.(2-3) has a different scale for A < 30 , or same figure, if starts with a very heavy nucleus (A = 240) and breaks it into two medium-size nuclei (fission), energy will be released because the average binding energy per nucleon is larger for nuclides in the middle of the periodic table than it is for heavy nuclides .

On the other hand, if one takes two very small nuclei **(**A =2 and 3) and fuses them into a larger one, energy is again released due to similar increase at the $B_{average}$ (binding energy per nucleon) [21].

It is noticed that for stable nuclei which are not too small, say for A > 12 the BE (binding energy) is in the first approximation symmetrical to the numeral of nucleons [71].

$$B\,(A\,,Z) \cong A \times 8\ MeV \text{ ,or to be exact,}$$

$$7.7\ MeV < B\,(A\,,Z)\,/\,A < 8.8\ MeV,\ \ 12 < A < 225$$

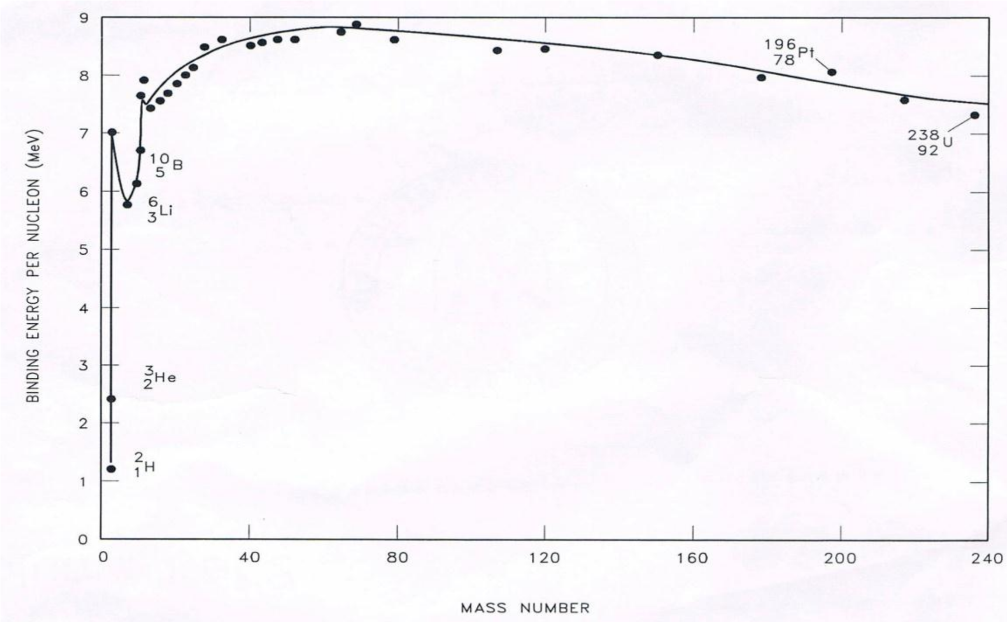


Fig.(2-3) Binding energy per nucleons of common isotopes[28].

The change of the rate binding energy per nucleon with mass number (A), in scale after A ≥ 30[43].

Energy needed to do to remove (or separated) a single neutron $S_n(\,^{A}_{Z}X)$ in nucleus $^{A}_{Z}X$,that energy is similar for the ionization energy necessary to move an external shell electron of an atom.

Energy of neutron separation equals the energy equivalent of the reduction in mass for the interaction[23] .

$S_n = [\, M\,(A\text{-}1, Z)\; + M_n - M\,(\,A, Z\,)]\, C^2$ ……………………………(2-26)

Can be expressed of separation energy from where nuclear binding energies Substitution of eq. (2-23) [23].

$S_n\,({}^{A}_{Z}X) = \; BE\,(\,A, Z\,) - BE\,(\,A - 1, Z\;)$ …………………………(2-**27)**

Separation energy for an alpha particle is:

$S_\alpha \; = [M\,(\,A - 4\,, Z{-}2\,) + \; M_\alpha - M(\,A\,, Z\,)]\, C^2$ ………………..(2-28)

or, using [21] :

$S_\alpha = BE\,(A\,, Z) - BE\,(A - 4, Z - 2) - BE\,(4\,, 2)$……………...(2-29)

(2-4)Reciprocity theory:

The cross sections for the interaction x (a, n) y are at a duties of measured E_a (E_a = Kinetic energy form a -particle) .

The cross sections of the inverse interaction y (n , a) x it may be estimate as the functions of $\mathbf{E_n}$ ($\mathbf{E_n}$ = Kinetic energy of (n)) use the reciprocity theorem indicate [67] :

$$\frac{\sigma_{(\alpha,n)}}{g_{\alpha,n}\,\lambdabar_{\alpha}^{2}} = \frac{\sigma_{(n,\alpha)}}{g_{n,\alpha}\,\lambdabar_{n}^{2}} \qquad \text{(2-30)}$$

where $\sigma_{(a,n)}$ and $\sigma_{(n,a)}$ appear cross sections of $(a\,, n)$ and $(n\,,a)$ interactions in running **, (g)** is a statistical factor and ($\lambdabar$) is the de–Broglie wave length divided by $\mathbf{2\pi}$ and is given by,

$$\lambdabar \;=\; \frac{\hbar}{Mv} \qquad \text{(2-31)}$$

Where : ħ = is Dirac constant (h /2π), h = is Planck constant,

Where : M and v = are mass and speed of α and n particle .

We have: $ƛ^2 = \frac{\hbar}{2Mv}$ ……………. ………. ….(2-32)

The statistical g-factors are givens by :

$$g_{a,n} = \frac{2J_c + 1}{(2Ix+1)(2I_a+1)}$$ ……………………(2-33)

And $$g_{n,\alpha} = \frac{2J_c + 1}{(2Iy+1)(2I_n+1)}$$ ……………………(2-34)

The conservation rule of the momentum that :

$$Ix + I_\alpha = J_c = Iy + I_n$$ ……………. ………. (2-35)

And, $$\pi x . \pi_\alpha (-1)^{l\alpha} = \pi_c = \pi_y . \pi_n (-1)^{ln}$$ ………….………….(2- 36)

π_c and J_c are the parity and the total angular momentum for the compound nucleus C [72].

π_X and I_X are the parity and the total angular momentum for nucleus x .

π_y and I_y are the parity and the total angular momentum for nucleus y.

π_α and I_α are the parity and the total angular momentum for $\alpha -$ particle.

π_n and I_n are the parity and the total angular momentum for neutron .

$$\pi_a = \pi_n = +1$$ ………..…………………..………… (2-37)

$$I_\alpha = S_\alpha + l_\alpha$$ ……..…………………...…………(2-38)

I_α is the total angular momentum of $\alpha -$ particle

S_α is the spin from $\alpha -$ particle = 0

l_α is the orbital angular momentum of $\alpha -$ particle

$$I_n = S_\alpha + l_n \qquad \text{.................................(2- 39)}$$

I_n is the total angular momentum of the neutron

S_n is the spin of neutron $= 1/2$

l_n is the orbital angular momentum of neutron

we have $$|J_c - I_X| \leq I_\alpha \leq J_c + I_X \qquad \text{................ .... (2- 40)}$$

And, $$|J_c - I_y| \leq I_n \leq J_c + I_y \qquad \text{.......................... .(2-41)}$$

The reactions x (α,n) y and y (n,α) x can be represented with the compound nucleus C as in the following schematic diagram. It is clear that there are some important and useful relations between the kinetic energies of the neutron and alpha particle. One can calculate the separation energies of α-particle (SE_α) and neutron (SE_n) using the following relations:

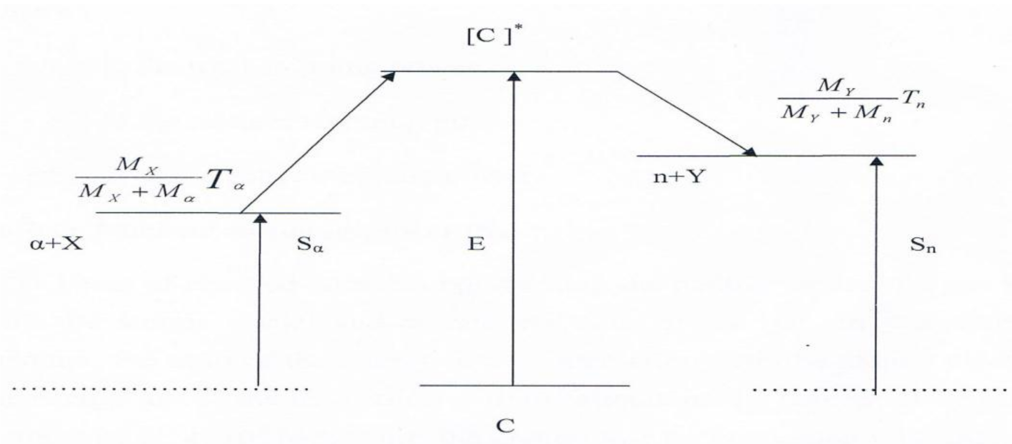


Fig.(2-4) Schematic diagram of the reactions x (α ,n) y [67].

SE_α and SE_n are separation energies of α and n from C. Then

$$E = SE_\alpha + \frac{M_A}{M_A + M_\alpha} T_\alpha \quad \text{.............. ....} \quad (2\text{-}42a)$$

$$E = SE_n + \frac{M_b}{M_b + M_n} T_n \quad \text{........................} (2\text{-}42b)$$

With :
$$SE_\alpha = 931.5 \left[M_A + Ma - M_c \right] \quad \text{..................................} (2\text{-}43)$$

$$SE_n = 931.5 \left[M_b + M_n - M_c \right] \quad \text{..................................} (2\text{-}44)$$

Combining (2-42a) , (2-42b) , (2-43) and (2-44), and

and as the Q- value of the reaction x (α ,n) y is given by:

$$Q_{\text{- value}} = [M_x + M_a - M_y - M_n]\ 931.5 \quad \text{........} (2\text{-}45)$$

then ,
$$Q = \frac{My}{My + M_n} T_n - \frac{M_X}{M_X + M_\alpha} T_\alpha \quad \text{...................} (2\text{-}46)$$

Or :
$$T_n = \frac{My + M_n}{My} \left[\frac{M_X}{M_X + M_a} T_a + Q \right] \quad \text{..................} (2\text{-}47)$$

Threshold energy E_{th} is given by:

$$E_{th} = \frac{M_x + M_a}{M_x} |-Q| \quad \text{........................ ....} (2\text{-}48a)$$

Or
$$Q = -E_{th} \frac{M_x}{M_x + M_a} \quad \text{...........................} (2\text{-}48b)$$

Then: $$T_n = \frac{M_y + M_n}{M_y} \times \frac{M_x}{M_x + M_a} \left(T_a - E_{th}\right) \quad \text{……….. (2- 49)}$$

Also eq., (2-30) can be written as follows :

$$\boldsymbol{\sigma}_{(n,a)} = \frac{g_{n,a} M_a T_a}{g_{a,n} M_n T_n} \sigma_{(a,n)} \quad \text{………………………..(2- 50)}$$

It is clear form this equation that the cross sections of reverse reaction are related by a variable parameters which can be calculated if the nuclear characteristics of the reactions are known [67].

(2-5) Cross Section :

The probability is expressed quantity ‘cross section, must be when goes the particle (Electron, Photon, Nuclei, Neutrino, Muons, Hadron) to any part of substance , it may be a certain probability to interact with the electrons or with the nuclei present in that substance, the dimension of area, is measured by the experimental ratio[73].

$$\boldsymbol{\sigma} = \frac{\text{The number of particles emitted from the reaction}}{(\text{number of ray particles per unit area})(\text{number of target nuclei inside the beam})}.$$

Unit for the cross section **(σ)** commonly are the barn and cm^2 where (1 barn = 10^{-24} cm^2 , = $10^{-28} m^2$), can be also calculated from a mathematical model of the nucleus are related by eq.(2-51), and show as fig.(2-6) :

$$d\,W = dx\, N\, \sigma \quad \text{………………………………….. (2- 51)}$$

dW : is the probability to undergo an interaction of certain type,

dx: is the thickness of a very thin section of the material ,

N : is the number of scattering centers per unit volume.

If the radiation of particles enters part of material, the number of affected particles in the radiation will increases due to the collisions of these beam particles with the electrons or nuclei present in the material.

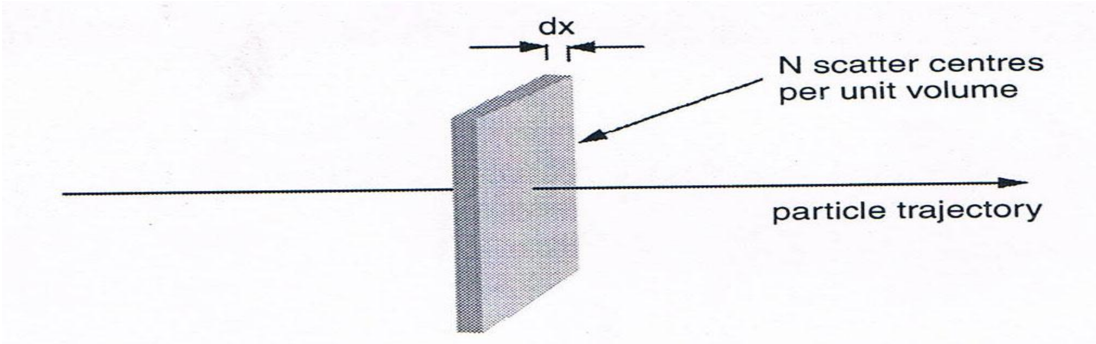


Fig.(2-5) Definition of the cross- section [73].

let us define way in mathematically as:

But we know that $P(x+\Delta x)$, $p(0) = 0$, and $P(x)$ where is related by:

$$P(X + \Delta x) = P(x) + [1 - P(x)]\, N\sigma\, \Delta x \quad \text{.……….(2- 52)}$$

$$\frac{P(X+\Delta x) - P(x)}{\Delta x} = [1 - P(x)]\, N\,\sigma \quad \text{..…………(2- 53)}$$

$P(x)$**:** is a probability interacted a particles after travelling

x: is a distance in the material

At that term Δx appear some small dimension in the (x) trend, taking the limit $\Delta x \to 0$, we gain that $P(x)$,we get at differential equation satisfies the following .

$$\frac{\Delta P(x)}{\Delta x} = [1 - P(x)]\, N\,\sigma \quad \text{……………..……….(2- 54)}$$

$$\frac{\Delta [1 - P(x)]}{\Delta X} = -\, [1 - P(x)]\, N\,\sigma \quad \text{…… ……….(2- 55)}$$

Differential equation can be solved :

with the limit state $[1-P(0)] = 1$, is $[1-p(x)]\ e^{-xN\sigma}$,

The probability intensity function for the reaction of a particle after a travelling space (x) in the material , is given via.

$$W(x) = [1 - P(x)]\, N\, \sigma = e^{-xN\sigma}\, N\, \sigma \quad \text{.........(2-56)}$$

The total cross sections provided by :

$$\sigma_{tot} = \int \frac{d\sigma}{d\Omega}\, d\Omega \quad \text{..................... ....(2-57)}$$

This is called a differential cross section and this is usually written as $d\boldsymbol{\sigma} / d\Omega$, where $d\Omega = \sin\theta\ d\theta\ d\varphi$ [73].

(2-6) Stopping power:

Both charged and uncharged particles lose energy while passing through matter, but stopping power describes only the energy loss of charged particles[66]. When a fast positive ion transport by material losing energy result it excite atomic electrons and ionization, it is necessary to know the energy loss per unit track from material, S, which is alternatively called stopping force or stopping power [67].

Consider any charged particle of type and kinetic energy dE, in a medium of atomic number Z . Called the expected value of energy loss rate per unit length is called the stopping power dE is the energy loss in dx :

(S) Stopping power = $-\, dE/dX$, are unit: $MeV.\, m^{-1}$ or $J.\, m^{-1}$.

Stopping power is divided into two parts depending on the energy lost by charged particles[20].

1. **Stopping power due to collision** :

   Collision interactions we mean the rate of energy loss of the sum of hard collisions and soft .

2. **Stopping power due to Radioactive :**

   stopping power and rate of energy loss from radioactive interactions depends on :[20].

   (a) the properties of the material it pass into.

   (b) the kind and energy particle [68].

(2- 6-1) Nuclear Stopping Power (S_n) :

When the fast charged particles pass over material, ionize the atom or molecule which they facing ,therefore, the fast particles imperceptibly lose energy by many small steps .

The average energy loss of the particle and measured per unit path length designated by the (- dE / dx) ,we mean "Stopping power".

Stopping power refers to the property of the material however energy loss per unit track length describes , what occur to the particle, however numerical values and units are corresponding for both amount, stopping power depends on the energy and kind of the particle and on the characteristics of the material it pass in which [74]. One can thus divide the total stopping power into three independent parts by:

$$S_t = S_{electronic} + S_{nuclear} + S_{radiative} \qquad \text{..................(2- 58)}$$

At projectile energies well below the speed of light, $S_{radiative}$ can be neglected [75].

The total stopping power $S_t\,(-dE/\,dx)$, is the sum of the electronic and neutron stopping power and nuclear stopping power as.

$$S_t = S_e + S_n \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}59)$$

S_e : is the stopping power of electrons target

S_n : is the stopping power of nuclei's target

For sufficiently high projectile energies, $S_t \approx S_e$,

S_n : is units eV/ (10^{15} atoms /cm^2), projectile with energy **E** (kev), is given by:

$$S_n(E) = \frac{8.462\, Z_1 Z_2 M_1 S_n(\varepsilon)}{(M_1+M_2)(Z_1^{0.23}+Z_2^{0.23})} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}60)$$

Where is the reduced ion energy, and defined as :

$$\varepsilon = \frac{32.53\, M_1 M_2 (E\,/M_1)}{Z_1 Z_2 (M_1+M_2)(Z_1^{0.23}+Z_2^{0.23})} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}61)$$

Where : E= ion energy in keV, For $\varepsilon \le 30$ keV,

M_1, M_2 = are the projectile and target masses (a.m.u),
Z_1, Z_2 = are the projectile and target atomic number.

$$S_n(\varepsilon) = \frac{\ln(1+1.1383\varepsilon)}{2[\varepsilon+0.01321\varepsilon^{0.21226}+0.19593\varepsilon^{0.5}]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}62)$$

Unsorted nuclear stopping is being used, and $S_n(\varepsilon)$ simplifying to

$$S_n(\varepsilon) = \frac{\ln \varepsilon}{2\varepsilon} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}63)$$

(S) can be converted to units of MeV/(mg/cm^2) by multiply in by 0.6022 / M_2 [76].

The nuclear stopping power (S_n) of the α-particle with different energy ranges have been presented by Ziegler as follows:

$$S_n = 1.593\varepsilon^{1/2} \quad (\varepsilon < 0.01 \text{ MeV}) \qquad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}64)$$

$$S_n = 1.7(\varepsilon^{1/2})\left[\frac{\ln(\varepsilon + \exp 1)}{1 + 6.8\varepsilon + 3.4\varepsilon^{3/2}}\right] (0.01 \le \varepsilon \le 10 \text{ MeV}) \ldots\ldots(2\text{-}65)$$

$$S_n = (\ln 0.47\varepsilon)/2\varepsilon \quad (\varepsilon > 10 \text{ MeV}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}66)$$

Where ε is the reduced ion energy which is given by[68]:

$$\text{Reduced Ion Energy} = \varepsilon = \frac{32.53 M_2 E}{Z_1 Z_2 (M_1 + M_2)(Z_1^{2/3} + Z_2^{2/3})^{1/2}} \quad \ldots(2\text{-}67)$$

E : is ion energy in keV, M_1 : is the mass of projectile in(a.m.u), M_2 : is the mass of target element in(a.m.u), Z_1 : is the atomic number of the projectile, Z_2 : is the atomic number of the target [76].

(2-6-2) Electronic Stopping Power (Se) :

Electronic stop refers to the slowing down projectile ion, causes the inelastic collisions among electrons bound in the medium and the ion moving through it . The electronic energy loss for ions has a peak at intermediate energies fig.(2-7).

At high projectile energies, the ion is stripped of its electrons and the situation can be a good approximation seen as coulomb scattering between the ion and electrons in the target[77].

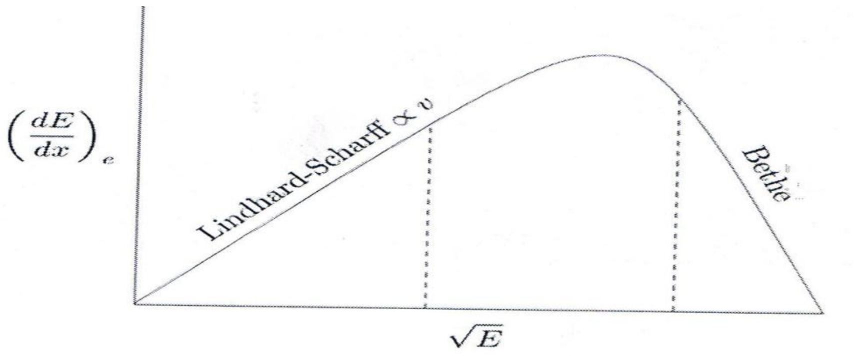


Fig.(2-6) Electronic Stopping Power [75].

In figure(2-7),notes the electronic stopping for slow ions is proportional to the velocity of the ion ,while for fast ions the electronic stopping decreases with increasing kinetic energy.

The stopping power is consequently found by solving the scattering integral . As expected, the maximum transfer of energy occurs in a head-on collision (θ = π) and when the projectile and atom are of equal mass .

We assume spherically symmetric potentials V(r), we can write the classical scattering integral as:

$$\theta = \pi - 2b \int_{r_{min}}^{\infty} \frac{dr}{r^2\left[1 - \frac{V(r)}{E_c} - \frac{b^2}{r^2}\right]} \qquad \text{............(2- 68)}$$

b: is the effect parameter, Ec in (CM) energy,

r = is the radial polar coordinate connecting the projectile to the atom.

In order to model the interactions we need to find an appropriate screening function Ø(r) for the coulomb potential by.

$$V(r) = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 r}\, \emptyset\,(r/a) \qquad \text{......................(2- 69)}$$

Where: a= is the represents a screening length, often dependent on the atomic numbers Z,

r/a = is called the reduced radius.

Use of the radius r/a makes the function F(r/a) in many classical inter atomic potentials independent of Z_1 and Z_2, by using eqs.(2-69). Without screening , and using NZ_2 as the electron density ,which gives:

$$\left(\frac{dE}{dX}\right)_e = N\, Z_2\, \pi\, \frac{Z_1^2\, \varepsilon^4}{E}\, \frac{m_1}{m_e}\, \ln\left(\frac{E}{\bar{I}}\right) \qquad \text{..............(2- 70)}$$

Where : g = is the kinematic factor $4m_1m_2 /(m_1+m_2)^2$,

$\bar{I}$ = is the average ionization energy.

At low projectile energies, the ion is close to neutral and the conduction electrons contribute more to the electronic energy loss.

This is because lower energies are needed to excite such electrons compared to inner shell electrons, given that the stopping power at low energies is proportional to the ion velocity.

$$\left(\frac{d\,E}{d\,X}\right)_e = 8\, \sigma_e N \left(\frac{m_e}{m_1}\right)^{1/2} E^{1/2} = K\, E^{1/2} \qquad \text{............(2-71)}$$

This expression gives a reasonable approximation in the low ion energy regime .

The electronic stopping powers were calculated by the Ziegler formula expressions valid for the energy range (10-140keV)[75].

$$\left(\frac{1}{S_e}\right) = \left(\frac{1}{S_{Low}}\right) + \left(\frac{1}{S_{High}}\right) \qquad \text{..........................(2-72)}$$

$$S_{Low} = A_1 E^{A_2} \qquad \text{.........................(2-73)}$$

$$S_{High} = \left(\frac{A_3}{E/1000}\right) \ln\left[1 + \left(\frac{A_4}{E/1000}\right) + \left(\frac{A_5 E}{1000}\right)\right] \qquad \text{................(2-74)}$$

Where : $\mathbf{A_i}$ = are coefficients given by Ziegler [78].

(2-6-3) Alpha – particle Stopping Power (S_α):

Alpha particle loses, on mean,(35.5 ev) per ion pair which produces, passing through air or soft tissue, this is due to its high electrical charge and relatively slow speed, and big mass ,the specific ionization of an alpha particle is high , generating a tens of thousands of ion pairs per centimeter in air . Alpha particles generally have a kinetic energy of about (5 MeV), and a velocity in the vicinity of (5% c) the speed of light [79]. The calculation for heavier charge particles like (p, d, and α), for the following as :

$$\frac{dT}{dX}(\mathrm{MeV} / \mathrm{m}) = 4\pi r_0^2 Z^2 \frac{mC^2}{\beta^2} N\, Z \left[\ln\left(\frac{2m\,C^2}{I}\beta^2\gamma^2\right) - \beta^2\right] \text{.........(2-75)}$$

Where: $r_0 = e^2 / mc^2 = 2.818 \times 10^{-15}$ m = classical electron radius,

$4\pi r_0^2 = 9.98 \times 10^{-29} m^2 \approx 10^{-28} m^2 = 10^{-24} cm^2$,

mc^2 : the rest bloc energy of the electron is (0.511 MeV),

$\gamma = (E + m c^2)/ m c^2 = 1/\sqrt{1 - \beta^2}$, m= rest mass of the particle,

E = kinetic energy $= (\gamma - 1) mc^2$, A = atomic weight,

$\beta = v/c$ (c= speed of light in vacuum

$= 2.997930 \times 10^8$ m /s $\approx 3 \times 10^8$ m/s,

N = number of atoms /m^3 in the material through which the particle moves,

$N = \rho(N_A /A)$, (N_A= Avogadro's number $= 6.022 \times 10^{32}$ atoms / mol,

Z: is the atomic number of the substance ,

z : is charge of the incident particle (z =1 for (e-,e+,p, d), z = 2 for α)

I : is mean excitation potential of the substance .

An approximate equation for; I, which gives good results for

$Z > 12$, is $I\,(\mathrm{eV}) = (9.76 + 58.8\, Z^{-1.19})\, Z$ [21].

(2-7) Neutron Yield :

The yield of a nuclear interaction is the proportion of the number of events of the nuclear interaction to the number of particles incident per($1cm^2$)of the target , for a thin aim and a identical particle influx.The yield is greater for nuclear interactions with high -energy particles. For particles that can be reason nuclear interactions at any energy (neutrons , peons), the yield with sufficiently big aims might reach (1) [19].

The probability of an accelerating beam traversing a target the occurred nuclear (α,n) reactions produce (N) light product particles per unit time, referring to fig. (2-8) the yield is given by:

$$Y(x) = I_o N_a \sigma x \quad \text{..........................(2-76)}$$

I_o : is the number of accident particles per unit time per unite area,

N_a : is the a actual number intensity of aim atomic ,

σ: is the cross section, and x: is the thickness.

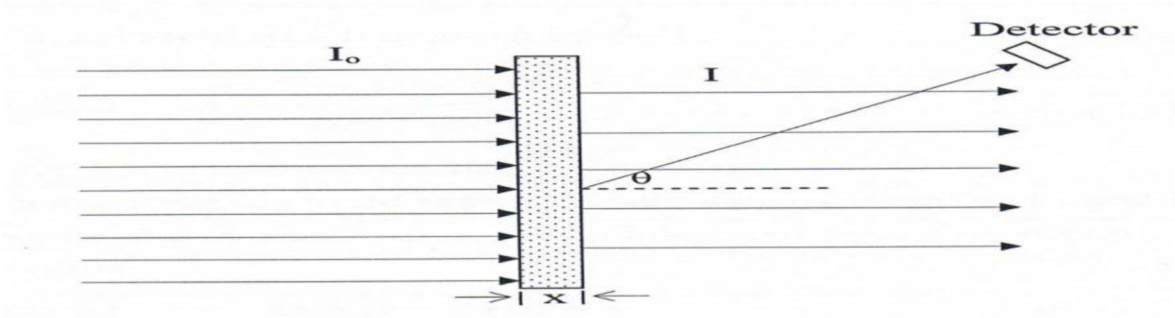


Fig (2-7) A schematic diagram of the definition of total cross section [79].

Experimentally, the yield from neutrons uncover per accident particle, Y_n , to an typical, thin and regular aim and monoenergetic radiation of energy (E) is given by [79]:

$$Y_n = (N_a x)\, \sigma\, (E_a)\, \eta(E_a) \quad \text{..........................(2-77)}$$

E_a: is the average of (E_1) and (E_2), η: is the neutron-detection efficient.

The aim whom is not infinitesimally, the radiation loses energy as it passes through the aim , and the yield is then given by:

$$Y_n = \int_{E_t}^{E_a} \frac{\sigma(\grave{E})\eta(\grave{E})\, i d\grave{E}}{-\frac{dE}{dX}(\grave{E})} \quad \ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots..(2\text{-}78)$$

In which: $E_t = E_a - \Delta E$ ……………………………… …….(2-79)

(ΔE) : is energy loss the aim ,

(n) : is the number of target atoms in each target molecule,

$-\frac{dE}{dX}(\grave{E})$: is the stopping power per target molecule [79].

If the aim enough thick, and there occur one atom per each molecule (i.e., $i = 1$) and taking $\eta(E`) = 1$, then the resulting yield is called the thick-target yield whom is given by .

$$Y(E_a) = \int_{E_{th}}^{E_\alpha} \frac{\sigma(E)dE}{-dE/dX} \quad \ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots..(2\text{-}80)$$

E_{th} : is the reaction threshold energy.

So, via measuring the yield at two carefully spaced energies (E_1) and (E_2), one can limit the rate value of the integrand over this energy period as follows :

$$\left[\frac{\sigma(E)}{-dE/dx}\right]_{Ea} = \frac{Y(E_2) - Y(E_1)}{E_2 - E_1} \quad \ldots\ldots\ \ldots\ldots\ldots\ldots\ldots..(2\text{-}81)$$

E_a: is the average of E_1 and E_2 .

If $\sigma(E)$ are ready as a function of projectile energy, (E_a) for normal elements, then the neutron yield can be calculated by eq.(2-80) [80].

If neutron yield is available as a function of projectile energy (E_a), then eq.(2-81) can be used to calculate $\sigma(E)$ as a function of (E_a) , can be also calculated the neutron yield using eq.(2-81) to one stable isotope is available in nature [80] .

$$Y_0 = Y(E) \qquad \ldots\ldots(2\text{-}82)$$

Where: (Y_o) = is the neutron yield per 10^6 bombarding particle for the natural element.

If $\sigma(E)$ is calculated for a certain isotope whose concentration (enrichment) is C % , then .

$$Y_0 = \frac{b}{c} Y(E) \qquad \ldots\ldots(2\text{-}83)$$

Where :

b = is the abundance of the isotope in the natural element .

If there exist more than one isotope that can be involved in the nuclear reaction and the cross sections are calculated as a function of incident energy for each isotope, then [81].

$$Y_o = \frac{b_1}{c_1} Y_1(E) + \frac{b_2}{c_2} Y_2(E) + \ldots \qquad \ldots\ldots(2\text{-}84)$$

(2-8) Nuclear Spin :

In classical mechanics, The particle has not only angular momentum but also direction [36].

In quantum mechanics and particle physics, a spin is an intrinsic form of angular momentum carried by elementary particles, composite particles (hadrons), of the atomic nuclei [29] . Quantum mechanical spin also contains information about direction, but in a more subtle form [22].

Spin is one of two types of angular momentum in quantum mechanics, the spin has been measured directly in experiments of the splitting of a beam of very slow neutrons in an inhomogeneous magnetic field, which the value ($\pm 1/2$) for the spin of the neutron, also it confirmed various facts , since the neutron is a particle with (half - integral spin), it obeys Fermi Dirac statistics, and the Pauli Exclusion Principle [36]. Value of spin for neutron as well as proton is ($s=\frac{1}{2}$) , and be ones pair with protons and neutrons pair with neutrons , neutrons of a pair line up opposite to each other resulting in (zero) spin and thus even number of neutrons in a nucleus will have all neutrons in pairs .The same is the case with an even number of protons , thus, for an (even –even) nucleus, the net nuclear angular momentum in the ground state will be zero[22].

The coupling of orbital angular momentum ($\boldsymbol{l}$) and spin (s) to give total angular momentum ($\boldsymbol{j}$). In atomic physics , a spin- orbit interaction splits the two degenerate $j = l \pm 1/2$. These values are presented in table (3-1)[23].

(2-9) Parity :

Parity is a nuclear property connected with the symmetry of the wave function . A system is said to have (odd or even) parity according to whether the function, wave or not, the system changes sign when the signs of all the space coordinates are changed .

If Ψ (x,y,z) = Ψ (-x,-y,-z),when (even) parity and

If Ψ (x,y,z) =$-\Psi$ (-x,-y,-z), when (odd) parity

The parity can take either (+) (even) or (−) (odd) values[22].

If we knew the wave function of every nucleon, we could determine the nuclear parity by multiplying together the equality of each of the nucleons, ending with a result (π) either (+ or −)[23].

$$\pi = \pi_1\pi_{2\ldots}\pi_A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}85)$$

The parity of an isolated system like its total energy, momentum, angular momentum .

The parity of a system is $(-1)^{l}$ where (l) is angular momentum quantum number, and (+) and (–) values correspond to even and odd parity respectively.

The parity conservation requires as:[22].

$$\pi_\alpha\pi_\times(-1)^{l\ \alpha,\times} = \pi_b\pi_y\ (-1)^{l\ b,y} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2\text{-}86)$$

Where: (π) = is the parity of each nuclear state.

This conservation law imposes limitation on the reaction probability, the reaction rate sometimes may be so minute that its occurrence cannot be detected with available equipment ,these values are presented in table. These values are presented in table (3-1) [23].

(2-10) The Half-Life:

The term half-life (t) is defined as the time it takes for one- half of the atoms of a radioactive material to disintegrate . The half –life is sometimes also called the half- value time . The time it takes for it to decay to one-half of the initial value($t_{1/2}$) is a constant called the half-life as:

$$N(t_{1/2}) = \frac{N_0}{2} = N_0 e^{-\lambda t_{1/2}} \quad \text{…………… ……….(2-87)}$$

Solving for $t_{1/2}$ yield ,

$$t_{1/2} = \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda} \quad \text{……………..………….(2-88)}$$

Where : $t_{1/2}$ = the half-life is independent of time t.

λ = is the total decay constant .

The half -life of α – emitter used in the present work has been taken from those reported by a table of isotopes, and as well as represents the basis of nuclear science and engineering for the sake of completeness, these values are presented in table (3-1). Any dynamic process governed by an exponential decay (or growth) has a remarkable property [24].

Chapter Three

Data Reduction and Analysis

Chapter Three

(3-1) The atomic mass of isotopes:

The atomic mass used for the isotopes of the elements mentioned in this study have been taken from the nuclear card sent out by the National Nuclear Data Center (NNDC) [82].Where the mass excess and packing fraction in (KeV) were calculated for each element using eq.(2-20) and (2-21) respectively and show in table (3-1), and abundance is given for stable isotopes from reference International Atomic Energy Agency (IAEA)[83]. For the sake of completeness, the atomic mass are expressed in (a.m.u), are given a spin , parity (J^{π}) and half- life in the down table .

Table (3 -1) The properties of nuclear used in the present work [82,83,84,85] :

Chem. Symbol	Atomic Mass (a.m.u) [82]	Mass Excess (keV) (p.w)	Packing Friction(p.w)	Abund. %[83]	J^{π} [84]	Half-life $t_{1/2}$ [85]
${}^{1}_{0}n$	1.0086645	8070.9817	8.64×10^{-3}	………	$1/2^{+}$	(12-15)min
${}^{1}_{1}p$	1.007825	7288.9875	7.825×10^{-3}	99.985	$1/2^{+}$	stable
${}^{4}_{2}He$	4.002603	2424.6945	6.507×10^{-4}	99.999	0^{+}	stable
${}^{139}_{57}La$	138.906348	-87236.8380	-6.741×10^{-4}	……	$7/2^{+}$	stable
${}^{141}_{59}Pr$	140.907648	-86025.8880	-6.553×10^{-4}	100	$5/2^{+}$	stable
${}^{142}_{59}Pr$	141.910040	-83797.740	-6.338×10^{-4}	………	2^{-}	19.12 h
${}^{143}_{59}Pr$	142.910812	-83078.622	-6.223×10^{-4}	………	$7/2^{+}$	13.57 d
${}^{144}_{61}Pm$	143.912586	-81426.141	-6.076×10^{-4}	………	5^{-}	363 d
${}^{145}_{61}Pm$	144.912744	-81278.964	-6.020×10^{-4}	………	$5/2^{+}$	17.7 y
${}^{144}_{62}Sm$	143.911995	- 81976.6575	-6.118×10^{-4}	3.1	0^{+}	stable
${}^{147}_{64}Gd$	146.919089	-75368.5965	-5.510×10^{-4}	100	$7/2^{-}$	38.06 h
${}^{148}_{64}Gd$	147.918110	-76280.535o	-5.533×10^{-4}	100	0^{+}	74.6 y

Table(3-1) Continued :

Chem. Symbol	Atomic Mass(a.m.u) [82]	Mass Excess (keV) (p.w)	Packing Fraction (p.w)	Abounds %[83]	J^{π} [84]	Half-life $t_{1/2}$ [85]
$^{159}_{65}Tb$	158.925343	- 69542.9955	-4.654×10^{-4}	100	$3/2^{+}$	stable
$^{162}_{67}Ho$	161.929092	-66050.802	-4.382×10^{-4}	………	1^{+}	15.0 m
$^{163}_{67}Ho$	162.928730	-66387.005	-4.374×10^{-4}	100	$7/2^{-}$	4570 y
$^{165}_{67}Ho$	164.930319	- 64907.8515	-4.18×10^{-4}	100	$7/2^{-}$	stable
$^{168}_{69}Tm$	167.934170	- 61320.6450	-3.869×10^{-4}	≈100	3^{+}	93.1 d
$^{169}_{69}Tm$	168.934211	- 61282.4535	-3.846×10^{-4}	100	$1/2^{+}$	stable
$^{172}_{71}Lu$	171.939082	-56745.117	-3.546×10^{-4}	………	4^{-}	6.70 d
$^{173}_{71}Lu$	172.938927	- 56889.4995	-3.531×10^{-4}	………	$7/2^{+}$	1.37 y

(3-2) Q-value ,threshold energies, binding energy ,and reduced mass:

The Q-$_{value}$ for (α, n) reaction have been calculated using eq.(2-2) in the present work and shown in the table (3-2), the maximum value of the reaction $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ about is(12.25 MeV),and the minimum value of the reaction $^{139}_{57}La\ (\alpha,n)^{142}_{59}Pr$ is about (9.08 MeV).

Also has been calculated threshold energy for the same reaction by using eq.(2-16) in the present work and shown in the table (3-2), the maximum value of the reaction $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ is about (12.59MeV), and the minimum value of the reaction $^{139}_{57}La\ (\alpha,n)^{142}_{59}Pr$ is about (9.34MeV). can been also calculated in the present work the coulomb barrier by using eq.(2-18) , Reduce mass barrier by using eq.(2-22) and Binding energy by using eq.(2-23) to target particles for the same reaction and shown in the table (3-2).

Table(3-2) Q-$_{value}$, threshold energy, binding energy, reduce mass and coulomb barrier for (α,n) reaction (in the ground state) :

REEs Reaction (α, n)	$Q_{0-Value}$ (MeV)(P.W)	Threshold Energy(MeV) (P.W)	Binding Energy (MeV) (p.w)	Reduced Mass(amu) (p.w)	Coulomb barrier (MeV)(pw
$^{139}_{57}\mathbf{La}\,(\alpha,n)^{142}_{59}\mathbf{Pr}$	− 9. 0853	9. 3468	1164. 4914	3. 8904	20. 2142
$^{141}_{59}\mathbf{Pr}\,(\alpha,n)^{144}_{61}\mathbf{Pm}$	−10.245	10. 5361	1177. 8584	3. 8920	20. 8471
$^{144}_{62}\mathbf{Sm}(\alpha,n)^{147}_{64}\mathbf{Gd}$	− 12.2538	12. 5942	1195. 6761	3. 8936	21.7897
$^{159}_{65}\mathbf{Tb}(\alpha,n)^{162}_{67}\mathbf{Ho}$	− 9. 1380	9. 3678	1301. 9556	3. 9042	22. 2701
$^{165}_{67}\mathbf{H0}(\alpha,n)\ ^{168}_{69}\mathbf{Tm}$	− 9. 2330	9. 4568	1344. 1805	3. 9077	22. 7368
$^{169}_{69}\mathbf{Tm}(\alpha,n)^{172}_{71}\mathbf{Lu}$	− 10.183	10. 4241	1371. 2741	3. 9094	23. 2709

(3-3) Separation energy of neutron in (α, n) reaction and Separation energy of inverse reaction alpha-particle in (n, α) reaction :

The calculated the separation energy of alpha particle (S_α) has been calculated using eq.(2-28) in the present work for compound nucleus in (α, n) reaction and shown in table (3-3),the maximum value of the reaction $^{144}_{62}\mathbf{Sm}(\alpha,n)^{147}_{64}\mathbf{Gd}$ is about (8.98MeV).

The separation energy of neutron (S_n) has been also calculated in the present work for compound nucleus in (n, α) reaction and shown in table (3-3) by using eq.(2-26), the maximum value is about (3.27MeV) of the reaction $^{147}_{64}\mathrm{Gd}(n,\alpha)^{144}_{62}\mathrm{Sm}$.

Table (3-3) Separation energy of neutron (S_n) and Separation energy of α-particle (S_α) (present work) :

RREs of (α,n) reaction	Compound Nuclide	S_n (MeV)	Inverse of (n,α) Reaction	Compound Nuclide	S_α (MeV)
$^{139}_{57}\mathbf{La}\ (\alpha,n)\,^{142}_{59}\mathbf{Pr}$	$^{143}_{59}Pr$	7.351	$^{142}_{59}Pr(n,\alpha)\,^{139}_{57}La$	$^{143}_{59}Pr$	-1.733
$^{141}_{59}\mathbf{Pr}\ (\alpha,n)\,^{144}_{61}\mathbf{Pm}$	$^{145}_{61}Pm$	7.923	$^{144}_{61}Pm(n,\alpha)\,^{141}_{59}Pr$	$^{145}_{61}Pm$	-2.322
$^{144}_{62}\mathbf{Sm}(\alpha,n)\,^{147}_{64}\mathbf{Gd}$	$^{148}_{64}Gd$	8.982	$^{147}_{64}Gd(n,\alpha)\,^{144}_{62}Sm$	$^{148}_{64}Gd$	-3.2714
$^{159}_{65}\mathbf{Tb}(\alpha,n)\,^{162}_{67}\mathbf{Ho}$	$^{163}_{67}Ho$	8.408	$^{162}_{67}Ho(n,\alpha)\,^{159}_{65}Tb$	$^{163}_{67}Ho$	-0.7302
$^{165}_{67}\mathbf{H0}(\alpha,n)\,^{168}_{69}\mathbf{Tm}$	$^{169}_{69}Tm$	8.032	$^{168}_{69}Tm(n,\alpha)\,^{165}_{67}Ho$	$^{169}_{69}Tm$	-1.2000
$^{169}_{69}\mathbf{Tm}(a.n)\,^{172}_{71}\mathbf{Lu}$	$^{173}_{71}Lu$	8.215	$^{172}_{71}Lu(a,n)\,^{169}_{69}Tm$	$^{173}_{71}Lu$	-1.968

(3-4) Cross Sections of (α,n) reaction :

The cross sections of (α,n) reaction for isotope ($^{139}_{57}La$, $^{141}_{59}Pr$, , $^{144}_{62}Sm$, $^{159}_{65}Tb$, $^{165}_{67}Ho$, and $^{169}_{69}Tm$,)which have atomic numbers (Z= 57, 59, 62, 65 , 67, and 69) available in the literature as mentioned in subsection (1- 6), have been taken ,and arranged tables (3- 4) to (3-9) and plotted as shown in fig.(3-1) to (3-18).And for the inverse reactions, they are arranged in tables (3-10) to (3-15) and figures (3-19) to (3-24).

These plots were analyzed using the Matlab computer program (version 7.6.0 R 2008a) to obtain the cross sections for different energy intervals as follows:

1- The cross section was determined by fine steps depending on reaction type which has been directly copied from the plots which show the variation of cross section with alpha particle energy.

2- Plots have been analyzed to obtain the formula for each reactions from the cross sections values for each author.

3- The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each author has been done.

4- The interpolation for the nearest data for each energy interval (0.2 MeV) as a function of cross sections by using the computer program Matlab (version7.6.0 R2008a).

(3-5) Stopping power :

The total stopping powers of elements with atomic numbers (Z=57,59,62, 65, 67 and 69), have been calculated in the present work using a computer program (SRIM- 2013)[86].

The results of this program is a first observation of the experimental stopping power, and second, it is active for energies needed in our calculations for incident alpha particle.Using the results in computer program (SRIM-2013) and eq.(2-59),where calculated the total stopping powers in unite(MeV/(mg/cm^2)) shown in tables (3-4) to (3-9).The present work of total stopping powers have been treated by spline, interpolated by fine steps and plotted as shown in figs(3-7) to (3-12).

(3-6) The Neutron Yield :

The thick target neutron yields from (α,n) reaction are very important quantity as well as the cross sections in analyzing problems of radiation shielding and safety in spent fuel [87].

Therefore, the thick target neutron yield for light elements ($^{139}_{57}$La , $^{141}_{59}$Pr , $^{144}_{62}$Sm , $^{159}_{65}$Tb , $^{165}_{67}$Ho , $^{169}_{69}$Tm) are calculated on the basis of the evaluated (α,n) reactions with the stopping power of alpha particle energy using eq.(2-81) .

Use cross sections from these (α,n) reactions have been used to obtain the neutron yields of the following reactions by using the eq.(2-81), and using computer program (SRIM-2013), shown in table (3- 4) to (3-9) and the results are plotted in figs.(3-13) to (3-18) with energy of alpha particle in steps (0.2 MeV) according to the nuclear reaction.

(3-7) Analysis for (α, n) reaction :

(3-7-1) The cross sections, stopping power and neutron yield of reaction $^{139}_{57}\mathbf{La}(\alpha,\mathbf{n})^{142}_{59}\mathbf{Pr}$:

The cross section of $^{139}_{57}\mathbf{La}(\alpha,\mathbf{n})^{142}_{59}\mathbf{Pr}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2 MeV) for alpha energy from (10.3 to 39.3) MeV , using Matlab (7.6.0R 2008a), as shown in table (3-4). From the results in table, we got the equation of (10th.) degree for plotted as shown in fig.(3-1) as follows :

$$\sigma = -2.3*10^{-10}*E^{10} + 5.8*10^{-8}*E^{9} - 6.5*10^{-6}*E^{8} + 0.00043*E^{7} - 0.018*E^{6} + 0.5*E^{5} - 9.6*E^{4} + 1.2*10^{2}*E^{3} - 1*10^{3}*E^{2} + 4.7*10^{3}*E - 9.6*10^{3} \quad \text{..........................(3-1)}$$

The stopping power of the Lanthanum element for alpha particles was calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) as shown in table (3-4).These data are plotted in fig.(3-7) and using eq.(2-59), we got equation of (10^{th}) degree as follows: $-\frac{dE}{dX} = -2.4*10^{-14}*E^{10} + 6.2*10^{-12}*E^{9} - 7*10^{-10}*E^{8}$

$$+ 4.6*10^{-8}*E^{7} - 1.9*10^{-6}*E^{6} + 5.3*10^{-5}*E^{5} - 0.00099*E^{4}$$

$$+0.012*E^{3} - 0.094*E^{2} + 0.39*E - 0.37 \quad \text{.....................(3-2)}$$

Also the neutron yield in unite (n /10^6 α-particle) have been calculated by using eq.(2-81). The results are listed in the table (3-4) and plotted in fig.(3-13) and we got equation of neutron yield (10th.) degree as follows:

$$Y(E_{\alpha}) = -3.6*10^{-10}*E^{10} + 9.2*10^{-8} * E^{9} - 1*10^{-5} * E^{8}$$

$$+ 0.00068*E^{7} - 0.028*E^{6} + 0.8* E^{5} - 15* E^{4} + 1.9* 10^{2}E^{3}$$

$$- 1.6*10^{3} * E^{2} + 7.3*10^{3} * E - 1.5*10^{4} \qquad \text{......................(3- 3)}$$

Table(3-4) The cross section ,stopping power and neutron yield for $^{139}_{57}La(\alpha, n)^{142}_{59}Pr$ reaction as a function of alpha energy with threshold energy (9.34670254)MeV :

Alpha energy (MeV)	Cross section of α-particle (barn)[p.w]	Stopping power (MeV/ (mg /cm^2)) [p.w]	Neutron Yield (n/$10^6\alpha - particle$) [p.w]
10.3	0.499	0.210	0.473
10.5	0.679	0.208	0.652
10.7	0.859	0.205	0.834
10.9	1.039	0.203	1.021
11.1	1.220	0.201	1.212
11.3	1.400	0.199	1.405
11.5	1.583	0.197	1.603
11.7	1.760	0.194	1.805
11.9	1.940	0.192	2.016
12.1	2.120	0.190	2.225
12.3	2.305	0.189	2.433
12.5	2.411	0.187	2.575
12.7	2.522	0.185	2.721
12.9	2.633	0.183	2.869
13.1	2.744	0.181	3.019
13.3	2.946	0.180	3.271
13.5	3.238	0.178	3.629
13.7	3.530	0.176	3.993
13.9	3.822	0.175	4.364
14.1	4.114	0.173	4.741

Table (3- 4) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[p.w]	Stopping power (MeV/ (mg /cm^2)) [p.w]	Neutron Yield (n/$10^6\alpha\ particle$) [p.w]
14.3	4.407	0.172	5.121
14.5	4.699	0.170	5.508
14.7	4.991	0.169	5.901
14.9	5.283	0.167	6.302
15.1	5.575	0.166	6.707
15.3	5.867	0.164	7.114
15.5	6.159	0.163	7.529
15.7	6.451	0.162	7.950
15.9	6.743	0.161	8.378
16.1	7.035	0.159	8.811
16.3	7.327	0.158	9.248
16.5	7.619	0.157	9.691
16.7	7.912	0.156	10.141
16.9	8.204	0.154	10.599
17.1	8.496	0.153	11.060
17.3	8.788	0.152	11.524
17.5	9.087	0.151	11.996
17.7	9.372	0.152	12.474
17.9	9.664	0.149	12.959
18.1	9.956	0.148	13.446
18.3	10.255	0.147	13.932
18.5	10.545	0.146	14.426
18.7	10.834	0.145	14.925
18.9	11.129	0.144	15.432
19.1	11.426	0.143	15.941
19.3	11.710	0.142	16.467
19.5	12.025	0.141	16.995
19.7	12.290	0.140	17.532
19.9	12.581	0.139	18.073
20.1	12.882	0.138	18.613
20.3	13.175	0.137	19.149
20.5	13.466	0.136	19.692
20.7	13.757	0.135	20.241
20.9	14.058	0.135	20.798
21.1	14.349	0.134	21.369
21.3	14.630	0.133	21.930
21.5	14.921	0.132	22.507
21.7	15.212	0.131	23.091
21.9	15.513	0.130	23.683
22.1	15.844	0.130	24.282

Table (3- 4) Continued:

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[p.w]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [p.w]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha}$ $\boldsymbol{particle}$) [p.w]
22.3	16.091	0.129	24.889
22.5	16.382	0.128	25.503
22.7	16.673	0.127	26.099
22.9	16.974	0.127	26.702
23.1	17.265	0.126	27.311
23.3	17.556	0.124	27.928
23.5	17.847	0.125	28.551
23.7	18.138	0.124	29.181
23.9	18.439	0.123	29.818
24.1	18.720	0.122	30.462
24.3	19.011	0.123	31.114
24.5	19.322	0.121	31.773
24.7	19.633	0.120	32.445
24.9	19.894	0.120	33.114
25.1	20.185	0.119	33.782
25.3	20.476	0.118	34.441
25.5	20.767	0.118	35.108
25.7	21.068	0.117	35.781
25.9	21.359	0.117	36.461
26.1	21.640	0.116	37.148
26.3	21.931	0.115	37.841
26.5	22.222	0.115	38.542
26.7	22.523	0.114	39.253
26.9	22.814	0.114	39.966
27.1	23.152	0.113	40.689
27.3	22.843	0.113	40.371
27.5	22.564	0.112	40.053
27.7	22.235	0.111	39.697
27.9	21.986	0.111	39.341
28.1	21.777	0.110	39.293
28.3	21.658	0.110	39.245
28.5	21.529	0.109	39.196
28.7	21.391	0.109	39.147
28.9	21.262	0.108	39.097
29.1	21.143	0.108	39.049
29.3	21.014	0.107	39.001
29.5	20.895	0.107	38.953
29.7	20.766	0.106	38.904
29.9	20.637	0.106	38.855

Table (3- 4) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[p.w]	Stopping power (MeV/ (mg /cm^2)) [p.w]	Neutron Yield (n/$10^6 \alpha\ particle$) [p.w]
30.1	20.517	0.105	38.795
30.3	20.384	0.105	38.725
30.5	20.264	0.104	38.653
30.7	20.132	0.104	38.582
30.9	20.013	0.103	38.509
31.1	19.885	0.103	38.436
31.3	19.756	0.103	38.362
31.5	19.630	0.102	38.287
31.7	19.522	0.102	38.212
31.9	19.382	0.101	38.136
32.1	19.250	0.101	38.062
32.3	19.134	0.100	37.983
32.5	19.120	0.100	37.905
32.7	18.546	0.099	37.129
32.9	18.085	0.099	36.346
33.1	17.617	0.099	35.558
33.3	17.150	0.098	34.763
33.5	16.695	0.098	33.961
33.7	16.234	0.097	33.153
33.9	15.763	0.097	32.339
34.1	15.350	0.097	31.518
34.3	14.726	0.096	30.443
34.5	14.144	0.096	29.364
34.7	13.550	0.095	28.268
34.9	12.978	0.095	27.166
35.1	12.390	0.095	26.050
35.3	12.014	0.094	25.347
35.5	11.833	0.094	25.065
35.7	11.660	0.094	24.782
35.9	11.483	0.093	24.497
36.1	11.305	0.093	24.209
36.3	11.454	0.094	24.624
36.5	11.605	0.096	25.043
36.7	11.750	0.092	25.464
36.9	11.901	0.091	25.889
37.1	11.280	0.091	24.645
37.3	10.672	0.091	23.392
37.5	10.053	0.090	22.129
37.7	9.439	0.090	20.848
37.9	8.823	0.091	19.558
38.1	8.208	0.089	18.258

Table (3- 4) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[p.w]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [p.w]	Neutron Yield (n/$\mathbf{10^6 \alpha}$ $\boldsymbol{particle}$) [p.w]
38.3	8.688	0.089	19.394
38.5	10.260	0.089	22.993
38.7	11.841	0.088	26.616
38.9	13.412	0.088	30.266
39.1	13.053	0.088	29.555
39.3	10.754	0.088	24.434
38.3	8.688	0.089	19.394
38.5	10.260	0.089	22.993

(3-7-2) The cross sections, stopping power and neutron yield of $\mathbf{{}^{141}_{59}Pr\ (\alpha, n)\ {}^{144}_{61}Pm}$ reaction :

The cross section of $\mathbf{{}^{141}_{59}Pr\ (\alpha, n)\ {}^{144}_{61}Pm}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2 MeV) for alpha energy from (15.9 to 44.3) MeV, using by Matlab program,as shown in the table (3-5). From the result ,we got the equation of (8^{th}) degree for plotted as shown in fig.(3-2) as follows :

$$\boldsymbol{\sigma} = -5.7*10^{-9}*E^8 + 1.4*10^{-6}*E^7 - 0.00014*E^6 + 0.0081*E^5$$

$$-0.29*E^4 + 6.4*E^3 - 87*E^2 + 6.6*10^2*E - 2.1*10^3 \quad \ldots\ldots\ldots\ldots(3\text{-}4)$$

The stopping power of the Praseodymium element for alpha particles was calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) , as shown in the table (3- 5) by using eq.(2-59), these data are plotted in fig. (3-8) , we got equation of (4^{th}) degree as follows:

$$-\frac{dE}{dX} = 7.8*10^{-8}*E^4 - 1.2*10^{-5}*E^3 + 0.00068*E^2$$

$$-0.02*E + 0.35 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}5)$$

Also the neutron yield in unite (n /10^6 α-particle) have been calculated by using eq.(2-81). The results are listed in the table (3-5) and plotted in fig.(3-14) and we got equation of neutron yield (5^{th}) degree as follows: $Y(E_\alpha) = 3.6*10^6*E^5 - 0.00061*E^4 + 0.04*E^3$

$$- 1.2*E^2 + 20E - 89 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}6)$$

Table(3-5) The cross section ,stopping power and neutron yield for $^{141}_{59}$Pr (α, n) $^{144}_{61}$Pm reaction as a function of alpha energy with threshold energy (10.53660269)MeV :

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) P.W]	Neutron Yield (n/$\mathbf{10^6 \alpha - \mathit{particle}}$) P.W]
15.9	19.795	0.159	24.876
16.1	19.684	0.157	24.931
16.3	19.573	0.156	24.977
16.5	19.462	0.155	25.024
16.7	19.351	0.154	25.072
16.9	19.242	0.153	25.121
17.1	19.129	0.152	25.162
17.3	19.019	0.151	25.195
17.5	18.908	0.149	25.229
17.7	18.797	0.148	25.263
17.9	18.686	0.147	25.297
18.1	18.575	0.146	25.322
18.3	18.464	0.145	25.337
18.5	18.353	0.144	25.352
18.7	18.242	0.143	25.367
18.9	18.132	0.142	25.383
19.1	18.021	0.141	25.398
19.3	17.912	0.140	25.414
19.5	17.799	0.141	25.435
19.7	17.688	0.139	25.446
19.9	17.577	0.138	25.463
20.1	17.466	0.137	25.465
20.3	17.355	0.136	25.454
20.5	17.244	0.135	25.442
20.7	17.134	0.134	25.433
20.9	17.023	0.133	25.418
21.1	16.912	0.133	25.406
21.3	16.801	0.132	25.393
21.5	16.692	0.131	25.381

Table (3-5) Continued:

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[p.w]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [p.w]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha}$ $\boldsymbol{particle}$) [p.w]
21.7	16.579	0.130	25.368
21.9	16.468	0.129	25.356
22.1	16.357	0.129	25.343
22.3	16.247	0.128	25.329
22.5	16.136	0.127	25.316
22.7	16.025	0.126	25.277
22.9	15.914	0.126	25.238
23.1	15.803	0.125	25.198
23.3	15.692	0.124	25.157
23.5	15.581	0.124	25.117
23.7	15.470	0.123	25.076
23.9	15.360	0.122	25.034
24.1	15.249	0.122	24.992
24.3	15.138	0.121	24.949
24.5	15.027	0.120	24.906
24.7	14.916	0.120	24.863
24.9	14.805	0.119	24.818
25.1	14.694	0.118	24.764
25.3	14.583	0.118	24.699
25.5	14.472	0.117	24.633
25.7	14.362	0.116	24.566
25.9	14.251	0.116	24.499
26.1	14.140	0.115	24.431
26.3	14.029	0.115	24.363
26.5	13.918	0.114	24.293
26.7	13.807	0.114	24.223
26.9	13.696	0.113	24.153
27.1	13.585	0.112	24.081
27.3	13.475	0.112	24.009
27.5	13.364	0.111	23.936
27.7	13.253	0.111	23.847
27.9	13.142	0.110	23.757
28.1	13.031	0.110	23.666
28.3	12.920	0.109	23.574
28.5	12.809	0.109	23.482
28.7	12.698	0.108	23.388
28.9	12.588	0.108	23.294
29.1	12.477	0.107	23.199
29.3	12.366	0.107	23.103
29.5	12.255	0.106	23.006
29.7	12.144	0.106	22.908

Table (3-5) Continued:

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[p.w]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [p.w]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha}\ \boldsymbol{particle}$) [p.w]
29.9	12.033	0.105	22.809
30.1	11.922	0.105	22.701
30.3	11.847	0.104	22.654
30.5	11.782	0.104	22.623
30.7	11.716	0.103	22.592
30.9	11.650	0.103	22.561
31.1	11.584	0.102	22.530
31.3	11.519	0.102	22.499
31.5	11.453	0.102	22.467
31.7	11.387	0.101	22.435
31.9	11.322	0.101	22.402
32.1	11.256	0.100	22.370
32.3	11.190	0.105	22.337
32.5	11.124	0.099	22.304
32.7	11.059	0.099	22.259
32.9	10.993	0.099	22.215
33.1	10.927	0.098	22.170
33.3	10.861	0.098	22.124
33.5	10.796	0.097	22.079
33.7	10.730	0.097	22.032
33.9	10.664	0.097	21.986
34.1	10.598	0.096	21.939
34.3	10.533	0.096	21.892
34.5	10.467	0.095	21.844
34.7	10.401	0.095	21.796
34.9	10.335	0.095	21.748
35.1	10.270	0.094	21.694
35.3	10.204	0.094	21.636
35.5	10.135	0.094	21.577
35.7	10.076	0.093	21.517
35.9	10.007	0.093	21.457
36.1	9.900	0.092	21.309
36.3	9.789	0.092	21.158
36.5	9.678	0.092	20.989
36.7	9.567	0.091	20.828
36.9	9.456	0.091	20.665
37.1	9.345	0.091	20.501
37.3	9.234	0.090	20.336
37.5	9.123	0.090	20.169
37.7	9.012	0.090	19.994
37.9	8.901	0.089	19.817

Table (3-5) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[p.w]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [p.w]	Neutron Yield (n/$\mathbf{10^6}\alpha\ \boldsymbol{particle}$) [p.w]
38.1	8.790	0.089	19.639
38.3	8.679	0.089	19.459
38.5	8.568	0.088	19.279
38.7	8.457	0.088	19.097
38.9	8.346	0.088	18.913
39.1	8.235	0.087	18.729
39.3	8.124	0.087	18.543
39.5	8.013	0.087	18.356
39.7	7.902	0.087	18.167
39.9	7.791	0.086	17.977
40.1	7.680	0.086	17.781
40.3	7.569	0.086	17.58
40.5	7.458	0.085	17.377
40.7	7.347	0.085	17.173
40.9	7.236	0.085	16.967
41.1	7.125	0.085	16.768
41.3	7.014	0.084	16.552
41.5	6.903	0.084	16.343
41.7	6.792	0.084	16.132
41.9	6.681	0.083	15.923
42.1	6.570	0.083	15.706
42.3	6.459	0.083	15.491
42.5	6.348	0.083	15.275
42.7	6.237	0.082	15.057
42.9	6.126	0.086	14.838
43.1	6.015	0.082	14.617
43.3	5.904	0.082	14.395
43.5	5.793	0.081	14.171
43.7	5.682	0.081	13.946
43.9	5.571	0.081	13.719
44.1	5.460	0.081	13.491
44.3	5.349	0.080	13.262
39.5	8.013	0.087	18.356
39.7	7.902	0.087	18.167
39.9	7.791	0.086	17.977
40.1	7.680	0.086	17.781
40.3	7.569	0.086	17.582
40.5	7.458	0.085	17.377
40.7	7.347	0.085	17.173
40.9	7.236	0.085	16.967
41.1	7.125	0.085	16.768

Table (3-5) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6 \alpha - \mathit{particle}}$) [P.W]
41.3	7.014	0.084	16.552
41.5	6.903	0.084	16.343
41.7	6.792	0.084	16.132
41.9	6.681	0.083	15.92
42.1	6.570	0.083	15.706
42.3	6.459	0.083	15.491
42.5	6.348	0.083	15.275
42.7	6.237	0.082	15.057
42.9	6.126	0.082	14.838
43.1	6.015	0.082	14.617
43.3	5.904	0.082	14.395
43.5	5.793	0.081	14.171
43.7	5.682	0.081	13.946
43.9	5.571	0.081	13.719
44.1	5.460	0.081	13.491
44.3	5.349	0.080	13.262

(3-7-3) The cross sections, stopping power and neutron yield of $\mathbf{{}^{144}_{62}Sm(\alpha,n){}^{147}_{64}Gd}$ reaction :

The cross section of $\mathbf{{}^{144}_{62}Sm(\alpha,n){}^{147}_{64}Gd}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha energy from (13.5 to 24.9) MeV ,using Matlab program, as shown in the table (3-6). From the results, we got the equation of (7^{th}) degree for plotted as shown in fig. (3-3) .

$$\boldsymbol{\sigma} = 0.0035*E^7 - 0.45*E^6 + 25*E^5 - 7.5*10^2*E^4 + 1.4*10^4*E^3$$

$$- 1.5*10^5*E^2 + 8.7*10^5*E - 2.2*10^6 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}7)$$

The stopping power of the Samarium element for alpha particles was calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) as shown in the table (3-6) by using eq.(2-59), these data are plotted in fig.(3-9), and we got equation of (8^{th}) degree as follows: $-\frac{dE}{dX} = -3.8*10^{-10} * E^8 + 5.9*10^{-8} * E^7 - 4*10^{-6} * E^6 + 0.00015*E^5 - 0.0035*E^4 + 0.052*E^3 - 0.48*E^2 + 2.4E - 5.1$ ....(3-8)

Also the neutron yield in unite (n/10^6 α- particle), have been calculated by using eq. (2-81). The results are listed in the table (3- 6) and plotted in fig.(3-15), and we got equation of (7th.) degree as follows:

$Y(E_\alpha) = 0.0052\, E^7 - 0.67\, E^6 + 37*E^5 - 1.1*10^3*E^4 + 2*10^4*E^3$

$-2.2*10^5*E^2 + 1.3*10^6 E - 3.2*10^6$ ....(3-9)

Table (3-6) The cross section ,stopping power and neutron yield of ${}^{144}_{62}\mathrm{Sm}(\alpha, n){}^{147}_{64}\mathrm{Gd}$ reaction as a function of alpha energy with threshold energy (12.59469792)MeV :

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6 \alpha particle}$) [P.W]
13.5	0.498	0.174	0.571
13.7	0.976	0.173	1.129
13.9	1.455	0.171	1.698
14.1	1.933	0.169	2.276
14.3	2.412	0.168	2.863
14.5	2.890	0.167	3.459
14.7	3.368	0.165	4.066
14.9	3.847	0.164	4.683
15.1	4.325	0.163	5.308
15.3	4.804	0.161	5.941
15.5	5.282	0.160	6.584
15.7	5.760	0.159	7.237
15.9	6.333	0.157	8.020
16.1	7.000	0.156	8.933
16.3	7.667	0.155	9.857
16.5	14.166	0.154	18.350
16.7	26.500	0.153	34.586
16.9	38.833	0.152	51.070
17.1	48.571	0.151	64.346
17.3	55.714	0.149	74.332
17.5	62.857	0.148	84.459

Table (3-6) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
17.7	70.000	0.147	94.732
17.9	77.142	0.146	105.153
18.1	84.285	0.145	115.679
18.3	91.428	0.144	126.298
18.5	94.370	0.143	131.221
18.7	93.125	0.142	130.335
18.9	91.880	0.142	129.438
19.1	90.630	0.141	128.528
19.3	88.500	0.140	126.358
19.5	85.500	0.139	122.900
19.7	82.500	0.138	119.395
19.9	96.910	0.137	141.209
20.1	128.700	0.136	188.765
20.3	160.500	0.135	236.799
20.5	192.400	0.134	285.398
20.7	224.181	0.134	334.562
20.9	256.000	0.133	384.331
17.7	70.000	0.147	94.732
17.9	77.142	0.146	105.153
18.1	84.285	0.145	115.679
18.3	91.428	0.144	126.298
18.5	94.370	0.143	131.221
18.7	93.125	0.142	130.335
18.9	91.880	0.142	129.438
19.1	90.630	0.141	128.528
19.3	88.500	0.140	126.358
19.5	85.500	0.139	122.900
19.7	82.500	0.138	119.395
19.9	96.910	0.137	141.209
20.1	128.701	0.136	188.765
20.3	160.500	0.135	236.799
20.5	192.400	0.134	285.398
20.7	224.181	0.134	334.562
20.9	256.000	0.133	384.331
21.1	249.000	0.132	376.060
21.3	242.000	0.131	367.689
21.5	235.000	0.130	359.216
21.7	228.000	0.131	350.640
21.9	274.800	0.129	425.206
22.1	321.600	0.128	500.691
22.3	334.700	0.127	524.322

Table (3-6) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
22.5	314.100	0.126	495.125
22.7	293.500	0.126	465.118
22.9	272.900	0.125	434.790
23.1	252.300	0.124	404.134
23.3	248.000	0.124	399.398
23.5	260.000	0.123	421.004
23.7	272.000	0.122	442.846
23.9	284.000	0.122	464.929
24.1	294.000	0.121	483.963
24.3	304.000	0.120	503.210
24.5	311.800	0.120	519.011
24.7	317.400	0.119	531.306
24.9	323.000	0.118	543.741

(3-7-4) The crosss ections,stopping power and neutron yield of $\mathbf{{}^{159}_{65}Tb(\alpha,n){}^{162}_{67}Ho}$ reaction :

The cross section of $\mathbf{{}^{159}_{65}Tb(\alpha,n){}^{162}_{67}Ho}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha energy from (15.8 to 46) MeV, using Matlab program, as shown in the table (3-7). From the results, we got the equation of (8^{th}) degree for plotted as shown in fig (3-4) as follows:

$$\boldsymbol{\sigma} = -1.1*10^{-8}*E^8 + 2.7*10^{-6}*E^7 - 0.00031*E^6$$
$$+0.19*E^5 - 0.73*E^4 + 17*E^3 - 2.5*10^2*E^2$$
$$+ 2.1*10^3\,E - 7.1*10^3 \quad \text{...(3-10)}$$

The stopping powers of the Terbium element for alpha particles was calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) as shown in the table (3-7) by using eq.(2-59), these data are plotted in fig.(3-10) and we got equation of (5^{th}) degree as follows:

$$-\frac{dE}{dX} = -1.9*10^{-9}*E^5 + 3.4*10^{-7}*E^4 - 2.6*10^{-5}*E^3$$

$$+ 0.001*E^2 - 0.024*E + 0.35 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3\text{- }11)$$

Also the neutron yield in unite (n/10^6 α- particle), have been calculated by using eq. (2-81). The results are listed in the table (3- 7) and plotted in fig.(3-16), and we got equation of (8^{th}) degree as follows:

$$(E_\alpha) = 1.9*10^8E^8 + 5*10^{6}*E^7 - 0.00056*E^6 + 0.035*E^5 - 1.4*E^4$$

$$+ 32*E^3 - 4.7*10^2E^2 + 3.9*10^3*E - 1.3*10^4 \quad \ldots\ldots\ldots\ldots(3\text{- }12)$$

Table (3-7) The cross section ,stopping power and neutron yield for $^{159}_{65}\mathbf{Tb}(\alpha,\mathbf{n})^{162}_{67}\mathbf{Ho}$ reaction as a function of alpha energy with threshold energy (9.366249911)MeV :

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
15.8	16.794	0.145	23.017
16.0	16.794	0.144	23.193
16.2	16.787	0.143	23.360
16.4	16.784	0.142	23.529
16.6	16.781	0.141	23.700
16.8	16.777	0.140	23.874
17.0	16.774	0.139	24.051
17.2	16.770	0.138	24.212
17.4	16.767	0.137	24.377
17.6	16.763	0.136	24.543
17.8	16.760	0.135	24.712
18.0	16.756	0.134	24.883
18.2	16.753	0.133	25.038
18.4	16.750	0.133	25.195
18.6	16.746	0.132	25.354
18.8	16.743	0.131	25.515
19.0	16.739	0.130	25.678
19.2	16.736	0.129	25.843
19.4	16.732	0.128	26.011
19.6	16.729	0.127	26.180
19.8	16.725	0.126	26.353
20.0	16.722	0.126	26.527
20.2	16.719	0.125	26.674

Table (3- 7) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}$$\boldsymbol{\alpha particle}$) [P.W]
20.4	16.715	0.124	26.823
20.6	16.712	0.123	26.973
20.8	16.708	0.123	27.125
21.0	16.705	0.122	27.279
21.2	16.701	0.121	27.435
21.4	16.698	0.121	27.593
21.6	16.694	0.120	27.752
21.8	16.691	0.119	27.914
22.0	16.687	0.118	28.077
22.2	16.684	0.118	28.242
22.4	16.681	0.117	28.410
22.6	16.677	0.116	28.567
23.0	16.670	0.115	28.860
23.2	16.667	0.114	29.008
23.4	16.663	0.114	29.159
23.6	16.660	0.113	29.311
23.8	16.656	0.113	29.465
24.0	16.653	0.112	29.620
24.2	16.650	0.111	29.777
24.4	16.646	0.111	29.936
24.6	16.641	0.110	30.097
24.8	16.639	0.111	30.259
25.0	16.636	0.109	30.423
25.2	16.638	0.108	30.563
25.4	16.623	0.108	30.703
25.6	16.625	0.107	30.845
25.8	16.622	0.107	30.988
26.0	16.619	0.106	31.133
26.2	16.615	0.106	31.279
26.4	16.612	0.105	31.426
26.6	16.608	0.105	31.575
26.8	16.602	0.104	31.725
27.0	16.601	0.104	31.877
27.2	16.456	0.103	31.758
27.4	16.170	0.103	31.363
27.6	15.884	0.102	30.954
27.8	15.597	0.102	30.533
28.0	15.311	0.101	30.107
28.2	15.025	0.101	29.678
28.4	14.738	0.100	29.245
28.6	14.452	0.100	28.808

Table (3- 7) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$10^6 \alpha particle$) [P.W]
28.8	14.165	0.099	28.367
29.0	13.879	0.099	27.921
29.2	13.593	0.099	27.472
29.4	13.306	0.095	27.018
29.6	13.020	0.096	26.561
29.8	12.734	0.097	26.099
30.0	12.447	0.097	25.632
30.2	12.161	0.096	25.146
30.4	11.875	0.096	24.65
30.6	11.588	0.095	24.163
30.8	11.302	0.095	23.664
31.0	11.015	0.095	23.162
31.2	10.729	0.094	22.656
31.4	10.443	0.094	22.145
31.6	10.225	0.093	21.775
31.8	10.075	0.093	21.547
32.0	9.925	0.093	21.318
32.2	9.775	0.092	21.086
32.4	9.625	0.092	20.853
32.6	9.475	0.091	20.613
32.8	9.325	0.091	20.365
33.0	9.175	0.091	20.115
33.2	9.025	0.090	19.864
33.4	8.875	0.090	19.611
33.6	8.725	0.090	19.355
33.8	8.575	0.089	19.098
34.0	8.425	0.089	18.838
34.2	8.275	0.089	18.577
34.4	8.125	0.088	18.313
34.6	7.975	0.088	18.047
34.8	7.825	0.088	17.779
35.0	7.675	0.087	17.509
35.2	7.525	0.087	17.229
35.4	7.375	0.087	16.947
28.8	14.169	0.099	28.367
29.0	13.875	0.099	27.921
29.2	13.592	0.099	27.472
29.4	13.308	0.098	27.018
29.6	13.025	0.098	26.561
29.8	12.731	0.097	26.099
30.0	12.447	0.097	25.632

Table (3- 7) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /cm^2)) [P.W]	Neutron Yield (n/$10^6 \alpha particle$) [P.W]
30.2	12.161	0.096	25.146
30.4	11.876	0.096	24.657
30.6	11.588	0.095	24.163
30.8	11.302	0.095	23.664
31.0	11.015	0.095	23.162
31.2	10.729	0.094	22.656
31.4	10.443	0.094	22.145
31.6	10.225	0.093	21.775
31.8	10.075	0.093	21.547
32.0	9.925	0.093	21.318
32.2	9.775	0.092	21.086
32.4	9.625	0.092	20.853
32.6	9.475	0.091	20.613
32.8	9.325	0.091	20.365
33.0	9.175	0.091	20.115
33.2	9.025	0.090	19.864
33.4	8.875	0.090	19.611
33.6	8.725	0.090	19.355
33.8	8.575	0.089	19.098
34.0	8.425	0.089	18.838
34.2	8.275	0.089	18.577
34.4	8.125	0.088	18.313
34.6	7.975	0.088	18.047
34.8	7.825	0.088	17.779
35.0	7.675	0.087	17.509
35.2	7.525	0.087	17.229
35.4	7.375	0.087	16.947
30.2	12.161	0.096	25.146
30.4	11.875	0.096	24.657
30.6	11.588	0.095	24.163
30.8	11.302	0.095	23.664
31.0	11.015	0.095	23.162
31.2	10.729	0.094	22.656
31.4	10.443	0.094	22.145
31.6	10.225	0.093	21.775
31.8	10.075	0.093	21.547
32.0	9.925	0.093	21.318
32.2	9.775	0.092	21.086
32.4	9.625	0.092	20.853
32.6	9.475	0.091	20.613
32.8	9.325	0.091	20.365

Table (3- 7) Continued:

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}$$\boldsymbol{\alpha particle}$) [P.W]
33.0	9.175	0.091	20.115
33.2	9.025	0.090	19.864
33.4	8.875	0.090	19.611
33.6	8.725	0.090	19.355
33.8	8.575	0.089	19.098
34.0	8.425	0.089	18.836
34.2	8.275	0.089	18.577
34.4	8.125	0.088	18.313
34.6	7.975	0.088	18.047
34.8	7.825	0.088	17.779
35.0	7.675	0.087	17.509
35.2	7.525	0.087	17.229
35.4	7.375	0.087	16.947
35.6	7.248	0.086	16.718
35.8	7.146	0.086	16.542
36.0	7.043	0.086	16.365
36.2	6.941	0.085	16.187
36.4	6.838	0.085	16.007
36.6	6.735	0.085	15.826
36.8	6.633	0.084	15.643
37.0	6.530	0.084	15.459
37.2	6.428	0.084	15.274
37.4	6.325	0.083	15.087
37.6	6.223	0.083	14.896
37.8	6.120	0.083	14.701
38.0	6.017	0.083	14.504
38.2	5.915	0.082	14.306
38.4	5.812	0.082	14.107
38.6	5.710	0.082	13.906
38.8	5.607	0.081	13.704
39.0	5.505	0.081	13.501
39.2	5.402	0.081	13.296
39.4	5.304	0.081	13.089
39.6	5.255	0.080	13.026
39.8	5.211	0.080	12.961
40.0	5.166	0.080	12.897
40.2	5.122	0.079	12.825
40.4	5.077	0.079	12.754
40.6	5.033	0.079	12.681
40.8	4.988	0.079	12.609
41.0	4.944	0.078	12.536

Table (3- 7) Continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
41.2	4.900	0.078	12.462
41.4	4.855	0.078	12.386
41.6	4.811	0.078	12.314
41.8	4.766	0.077	12.239
42.0	4.722	0.077	12.163
42.2	4.677	0.077	12.087
42.4	4.633	0.077	12.011
42.6	4.588	0.076	11.934
42.8	4.544	0.076	11.857
43.0	4.525	0.076	11.779
43.2	4.464	0.076	11.724
43.4	4.429	0.075	11.670
43.6	4.394	0.075	11.615
43.8	4.358	0.075	11.559
44.0	4.323	0.075	11.503
44.2	4.288	0.074	11.447
44.4	4.252	0.074	11.391
44.6	4.217	0.074	11.334
44.8	4.182	0.074	11.276
45.0	4.147	0.073	11.219
45.2	4.111	0.073	11.154
45.4	4.076	0.073	11.090
45.6	4.041	0.073	11.025
45.8	4.005	0.073	10.959
46.0	3.970	0.072	10.894

(3-7-5) The cross sections, stopping power and neutron yield of $^{165}_{67}\mathbf{Ho}(\alpha,\mathbf{n})\,^{168}_{69}\mathbf{Tm}$ reaction :

The cross section of $^{165}_{67}\mathbf{Ho}(\alpha,\mathbf{n})\,^{168}_{69}\mathbf{Tm}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha energy from (19.5 to 37.8) MeV,using Matlab program, as shown in the table (3-8). From the results we got, the equation of (4^{th}) degree for plotted as shown in fig.(3-5) as follows:

$\boldsymbol{\sigma} = -\,0.0064{*}E^4{+}0.76{*}E^3{-}32{*}E^2{+}5.8{*}10^2{*}E - 3.5{*}10^3$ ....(3-13)

The stopping power of the Holmium element for alpha particles include was calculated in the same range of alpha energy and in the same interval of energy (0.2 MeV) as shown in the table (3-8),by using eq.(2-59), these data are plotted in fig.(3-11) and we got equation of (9^{th}) degree as follows:

$$-\frac{\mathbf{dE}}{\mathbf{dX}} = -\,1.5{*}10^{-12} * E^9 + 3.7{*}10^{-10}{*}E^8 - 4.2{*}10^{-8} * E^7$$

$$+\ 2.7{*}10^{-6}{*}E^7 - 0.00011{*}E^5{+}0.0031{*}E^4$$

$$- 0.57{*}E^3 + 0.66{*}E^2 - 4.5 * E{+}13 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}14)$$

Also the neutron yield in unite (n/10^6 alpha particle) have been calculated by using eq.(2-81) . The results are listed in the table (3-8) and plotted in fig.(3-17), and we got equation of degree is cubic spline interplant .

Table(3-8)The cross section, stopping power and neutron yield for $^{165}_{67}Ho(\alpha,n)\,^{168}_{69}Tm$ the function of alpha energy reaction with E_{th} is (9.456)MeV :

α-energy (MeV)	Cross section of particle(barn)[p.w]	Stopping power (MeV/(mg/cm^2))[p.w]	Neutron Yield (n/10^6 α $particle$)[p.w]
19.5	191.045	0.049	768.572
19.7	187.463	0.049	759.944
19.9	183.881	0.049	751.182
20.1	180.300	0.048	741.798
20.3	176.718	0.048	731.796
20.5	173.136	0.048	721.664
20.7	169.554	0.047	711.398
20.9	165.972	0.047	700.995
21.1	162.399	0.047	690.453
21.3	158.801	0.046	679.770
21.5	155.273	0.046	668.941
21.7	151.645	0.046	657.965
21.9	148.063	0.045	646.838
22.1	144.481	0.045	635.557
22.3	140.900	0.045	624.119
22.5	137.318	0.044	612.520
22.7	133.736	0.044	600.035
22.9	130.154	0.044	587.403
23.1	126.572	0.044	574.621
23.3	122.990	0.043	561.687
23.5	119.409	0.043	548.597
23.7	115.827	0.043	535.350
23.9	112.245	0.043	521.942
24.1	108.663	0.042	508.371
24.3	105.081	0.042	494.633
24.5	101.500	0.042	480.725
24.7	97.918	0.042	466.644
24.9	94.336	0.041	452.387

Table (3-8) continued :

α -energy (MeV)	Cross sections of α-particle(barn) [p.w]	Stopping power (MeV/(mg/cm^2))[p.w]	Neutron Yield (n/10^6 α $particle$)[p.w]
25.1	90.754	0.041	437.739
25.3	87.172	0.041	422.714
25.5	83.590	0.041	407.528
25.7	80.009	0.040	392.178
25.9	76.427	0.040	376.660
26.1	72.845	0.040	360.972
26.3	69.263	0.040	345.112
26.5	65.681	0.039	329.076
26.7	62.100	0.039	312.862
26.9	58.518	0.039	296.466
27.1	54.936	0.039	279.886
27.3	51.354	0.039	263.118
27.5	47.772	0.038	246.160
27.7	44.190	0.038	228.817
27.9	40.609	0.038	211.304
28.1	37.027	0.038	193.618
28.3	33.445	0.038	175.756
28.5	29.863	0.037	157.716
28.7	26.281	0.037	139.496
28.9	22.700	0.037	121.092
29.1	19.118	0.037	102.501
29.3	15.536	0.037	83.721
29.5	11.954	0.036	64.745
29.7	8.372	0.036	45.582
29.9	4.790	0.036	26.217
30.1	2.963	0.036	16.297
30.3	2.891	0.036	15.971
30.5	2.818	0.036	15.641
30.7	2.746	0.035	15.309

Table (3-8) continued :

α -energy (MeV)	Cross sections of α-particle(barn)[p.w]	Stopping power (MeV/(mg/cm^2))[pw	Neutron Yield (n/$10^6 \alpha - particle$) [p.w]
30.9	2.673	0.035	14.974
31.1	2.601	0.035	14.635
31.3	2.528	0.035	14.294
31.5	2.456	0.035	13.949
31.7	2.383	0.035	13.601
31.9	2.311	0.034	13.249
32.1	2.238	0.034	12.895
32.3	2.166	0.034	12.537
32.5	2.093	0.034	12.175
32.7	2.021	0.034	11.803
32.9	1.948	0.034	11.428
33.1	1.876	0.034	11.049
33.3	1.803	0.033	10.668
33.5	1.731	0.033	10.283
33.7	1.658	0.033	9.894
33.9	1.586	0.033	9.503
34.1	1.513	0.033	9.108
34.3	1.441	0.033	8.709
34.5	1.368	0.033	8.307
34.7	1.296	0.032	7.902
34.9	1.223	0.032	7.493
35.1	1.151	0.032	7.078
35.3	1.078	0.032	6.658
35.5	1.006	0.032	6.235
35.7	0.933	0.032	5.809
35.9	0.861	0.032	5.379
36.1	0.788	0.031	4.946
36.3	0.716	0.031	4.509
36.5	0.643	0.031	4.069

Table (3-8) continued :

α -energy (MeV)	Cross sections of α-particle(barn)[p.w]	Stopping power (MeV/(mg/cm^2))[pw]	Neutron Yield (n/$10^6 \alpha - particle$) [p.w]
36.7	0.571	0.031	3.625
36.9	0.498	0.031	3.178
37.1	0.426	0.031	2.727
37.3	0.353	0.031	2.272
37.5	0.281	0.031	1.814
37.7	0.208	0.030	1.351

(3-7-6) The cross sections, stopping power and neutron yield of ${}^{169}_{69}\mathrm{Tm}(\alpha,n){}^{172}_{71}\mathrm{Lu}$ reaction :

The cross section of ${}^{169}_{69}\mathrm{Tm}(\alpha,n){}^{172}_{71}\mathrm{Lu}$ reaction have been plotted, spline interpolated and recalculated in fine steps (0.2MeV) for alpha

energy from (20.2 to 65.4) MeV ,using Matlab program, as shown in the table (3-9). From the results in the same table, we got the equation of (9^{th}) degree for plotted as shown in fig.(3-6) as follows:

$$\sigma = -3.8*10^{-11}*E^9 + 1.6*10^{-8}*E^8 - 2.9\,10^{-6}*E^7 + 0.0003\,E^6$$

$$-0.02*E^5 + 0.85*E^4 - 24*E^3 + 4.3*10^2*E^2$$

$$-4.4*10^3*E + 2*10^4 \quad \text{.......,...}(3\text{-}15)$$

The stopping power of the Thulium element for alpha particles include are calculated in the same range of alpha energy and in the same interval of energy (0.2MeV) as shown in the table (3-9), by using eq.(2-59), these data are plotted in fig.(3-12), and we got equation of cubic degree as follows:

$$-\frac{dE}{dX} = -6.2*10^{-7}*E^3 + 0.00011*E^2 - 0.0069*E + 0.22 \quad \text{..........}(3\text{-}16)$$

Also the neutron yield in unite (n/10^6 α- particle), have been calculated by using eq. (2-81). The results are listed in the table (3- 9) and plotted in fig.(3-18), and we got equation of (5th.) degree as follows

$$Y(E_\alpha) = -4*10^6E^5 + 0.00098*E^4 - 0.095*E^3 + 4.6*E^2$$

$$-1.1*10^2E\ \ 1.1*E^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}17)$$

Table(3-9) The cross section ,stopping power and neutron yield for $^{169}_{69}Tm(\alpha,n)^{172}_{71}Lu$ reaction as a function of alpha energy with threshold energy (10.42443026)MeV :

Alpha energy (MeV)	Cross section of **α**-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}$$\boldsymbol{\alpha particle}$) [P.W]
20.2	60.179	0.120	100.053
20.4	58.278	0.119	97.444
20.6	56.378	0.118	94.806
20.8	54.477	0.118	92.137
21.0	52.577	0.117	89.437
21.2	50.676	0.116	86.706
21.4	48.775	0.116	83.943
21.6	46.875	0.115	81.147
21.8	44.974	0.114	78.319
22.0	43.074	0.114	75.456
22.2	41.173	0.113	72.559
22.4	39.272	0.112	69.627
22.6	37.372	0.112	66.629
22.8	35.471	0.111	63.567
23.0	33.571	0.111	60.474
23.2	31.670	0.110	57.348
23.4	29.770	0.109	54.189
23.6	29.287	0.109	53.591
23.8	28.804	0.108	52.987
24.0	28.321	0.108	52.376
24.2	27.838	0.107	51.759
24.4	27.355	0.107	51.135
24.6	26.872	0.106	50.505
24.8	26.389	0.105	49.867
25.0	25.906	0.105	49.223
25.2	25.423	0.104	48.535

Table (3-9) continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
25.4	24.940	0.104	47.840
25.6	24.457	0.103	47.139
25.8	23.974	0.103	46.431
26.0	23.492	0.102	45.716
26.2	23.009	0.102	44.994
26.4	22.526	0.101	44.266
26.6	22.043	0.101	43.532
26.8	21.560	0.100	42.786
27.0	21.077	0.100	42.036
27.2	20.594	0.099	41.277
27.4	20.111	0.099	40.512
27.6	19.628	0.098	39.725
27.8	19.145	0.098	38.918
28.0	18.662	0.097	38.104
28.2	18.179	0.097	37.282
28.4	17.696	0.097	36.453
28.6	17.213	0.096	35.617
28.8	16.731	0.096	34.774
29.0	16.248	0.095	33.922
29.2	15.765	0.095	33.063
29.4	15.282	0.094	32.196
29.6	14.799	0.094	31.322
29.8	14.316	0.094	30.439
30.0	13.833	0.093	29.548
30.2	13.350	0.093	28.633
30.4	12.867	0.092	27.710
30.6	12.384	0.092	26.780
30.8	11.901	0.092	25.842
31.0	11.418	0.091	24.897
31.2	10.935	0.091	23.943
31.4	10.452	0.091	22.982
31.6	9.973	0.090	22.012
31.8	9.839	0.090	21.816
32.0	9.708	0.089	21.617
32.2	9.578	0.089	21.418
32.4	9.447	0.089	21.216
32.6	9.317	0.088	21.008
32.8	9.186	0.088	20.792
33.0	9.059	0.089	20.576
33.2	8.925	0.087	20.357
33.4	8.794	0.087	20.137

Table (3-9) continued :

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
33.6	8.664	0.087	19.915
33.8	8.533	0.086	19.691
34.0	8.403	0.086	19.466
34.2	8.272	0.086	19.239
34.4	8.142	0.085	19.010
34.6	8.011	0.085	18.779
34.8	7.880	0.085	18.546
35.0	7.750	0.084	18.312
35.2	7.619	0.084	18.068
35.4	7.489	0.084	17.822
35.6	7.358	0.083	17.575
35.8	7.228	0.083	17.325
36.0	7.097	0.083	17.074
36.2	6.966	0.082	16.821
36.4	6.836	0.082	16.567
36.6	6.705	0.082	16.310
36.8	6.575	0.081	16.052
37.0	6.444	0.081	15.791
37.2	6.316	0.081	15.529
37.4	6.183	0.081	15.264
37.6	6.052	0.080	14.995
37.8	5.922	0.080	14.722
38.0	5.791	0.080	14.446
38.2	5.661	0.079	14.169
38.4	5.530	0.079	13.889
38.6	5.456	0.079	13.608
38.8	5.368	0.079	13.554
39.0	5.329	0.078	13.499
39.2	5.280	0.078	13.444
39.4	5.241	0.078	13.389
39.6	5.242	0.078	13.333
39.8	5.163	0.077	13.277
40.0	5.124	0.077	13.221
40.2	5.085	0.077	13.158
40.4	5.046	0.077	13.094
40.6	5.187	0.076	13.030
40.8	4.966	0.076	12.966
41.0	4.925	0.076	12.901
41.2	4.884	0.076	12.836
41.4	4.843	0.075	12.770
41.6	4.824	0.075	12.704

Table (3-9) continued:

Alpha energy (MeV)	Cross section of $\boldsymbol{\alpha}$-particle (barn)[P.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$\mathbf{10^6}\boldsymbol{\alpha particle}$) [P.W]
41.8	4.761	0.0753	12.638
42.0	4.722	0.0751	12.571
42.2	4.683	0.0749	12.504
42.4	4.644	0.0746	12.436
42.6	4.65	0.0744	12.368
42.8	4.566	0.0741	12.300
43.0	4.527	0.0739	12.231
43.2	4.488	0.0737	12.161
43.4	4.449	0.0734	12.092
43.6	4.401	0.0732	12.021
43.8	4.361	0.073	11.951
44.0	4.322	0.072	11.879
44.2	4.283	0.072	11.802
44.4	4.244	0.072	11.736
44.6	4.256	0.072	11.663
44.8	4.164	0.071	11.590
45.0	4.123	0.071	11.526
45.2	4.095	0.071	11.464
45.4	4.056	0.071	11.402
45.6	4.023	0.071	11.340
45.8	3.995	0.070	11.278
46.0	3.956	0.070	11.215
46.2	3.923	0.070	11.152
46.4	3.890	0.070	11.088
46.6	3.856	0.077	11.024
46.8	3.823	0.069	10.960
47.0	3.792	0.069	10.895
47.2	3.756	0.069	10.830
47.4	3.723	0.069	10.765
47.6	3.692	0.069	10.699
47.8	3.656	0.068	10.633
48.0	3.623	0.068	10.566
48.2	3.594	0.068	10.499
48.4	3.556	0.068	10.432
48.6	3.523	0.068	10.366
48.8	3.491	0.067	10.296
49.0	3.456	0.067	10.227
49.2	3.423	0.067	10.159
49.4	3.392	0.067	10.089
49.6	3.356	0.067	10.024
49.8	3.323	0.066	9.949

Table (3-9) continued :

Alpha energy (MeV)	Cross section of α-particle (barn)[P.W]	Stopping power (MeV/ (mg /cm^2)) [P.W]	Neutron Yield (n/$10^6 \alpha particle$) [P.W]
50.0	3.294	0.066	9.879
50.2	3.256	0.066	9.804
50.4	3.223	0.066	9.728
50.6	3.194	0.066	9.652
50.8	3.177	0.065	9.639
51.0	3.164	0.065	9.625
51.2	3.152	0.066	9.612
51.4	3.139	0.065	9.598
51.6	3.127	0.065	9.585
51.8	3.114	0.065	9.571
52.0	3.102	0.064	9.557
52.2	3.089	0.064	9.543
52.4	3.077	0.064	9.529
52.6	3.064	0.064	9.515
52.8	3.052	0.064	9.501
53.0	3.039	0.064	9.487
53.2	3.026	0.063	9.473
53.4	3.014	0.063	9.459
53.6	3.001	0.063	9.444
53.8	2.989	0.063	9.430
54.0	2.976	0.063	9.416
54.2	2.964	0.063	9.401
54.4	2.951	0.062	9.386
54.6	2.939	0.062	9.372
54.8	2.926	0.062	9.357
55.0	2.913	0.062	9.342
55.2	2.901	0.062	9.323
55.4	2.888	0.062	9.305
55.6	2.876	0.061	9.286
55.8	2.862	0.061	9.264
56.0	2.847	0.061	9.237
56.2	2.832	0.061	9.210
56.4	2.817	0.061	9.183
56.6	2.802	0.061	9.156
56.8	2.787	0.061	9.128
57.0	2.772	0.060	9.101
57.2	2.757	0.060	9.073
57.4	2.742	0.060	9.046
57.6	2.727	0.060	9.018
57.8	2.712	0.060	8.990
58.0	2.697	0.060	8.962
58.2	2.682	0.060	8.934

Table (3-9) continued:

Alpha energy (MeV)	Cross section of α-particle (barn)[.W]	Stopping power (MeV/ (mg /$\mathbf{cm^2}$)) [P.W]	Neutron Yield (n/$10^6 \alpha particle$) [P.W]
58.4	2.667	0.059	8.905
58.6	2.652	0.059	8.877
58.8	2.637	0.059	8.848
59.0	2.622	0.059	8.824
59.2	2.607	0.059	8.791
59.4	2.592	0.059	8.764
59.6	2.577	0.059	8.732
59.8	2.562	0.058	8.703
60.0	2.547	0.058	8.674
60.2	2.532	0.058	8.641
60.4	2.517	0.058	8.609
60.6	2.506	0.058	8.589
60.8	2.498	0.058	8.581
61.0	2.490	0.058	8.577
61.2	2.483	0.058	8.565
61.4	2.475	0.057	8.558
61.6	2.467	0.057	8.550
61.8	2.464	0.057	8.542
62.0	2.452	0.057	8.534
62.2	2.444	0.057	8.526
62.4	2.436	0.057	8.519
62.6	2.429	0.057	8.511
62.8	2.421	0.057	8.503
63.0	2.413	0.056	8.495
63.2	2.406	0.056	8.486
63.4	2.398	0.056	8.477
63.6	2.390	0.056	8.470
63.8	2.383	0.056	8.462
64.0	2.375	0.056	8.454
64.2	2.367	0.056	8.446
64.4	2.364	0.055	8.437
64.6	2.352	0.055	8.429
64.8	2.344	0.055	8.421
65.0	2.336	0.055	8.412
65.2	2.329	0.055	8.402
65.4	2.321	0.055	8.391

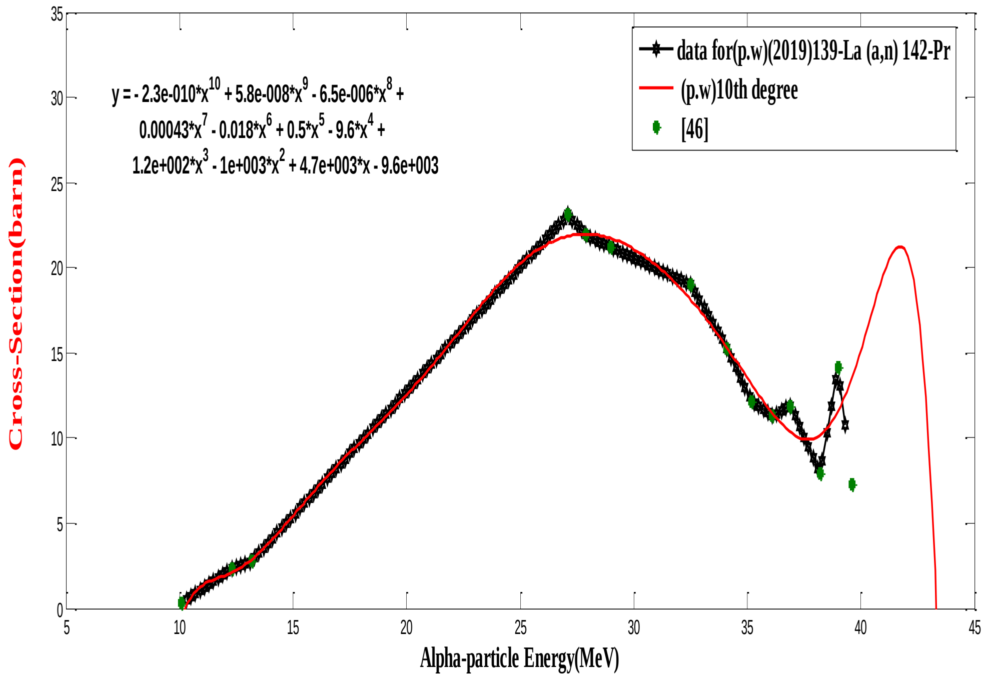


Fig.(3-1) The cross sections of $^{139}_{57}La(\alpha, n)\ ^{142}_{59}Pr$ reaction by fitting and interpolation (p.w).

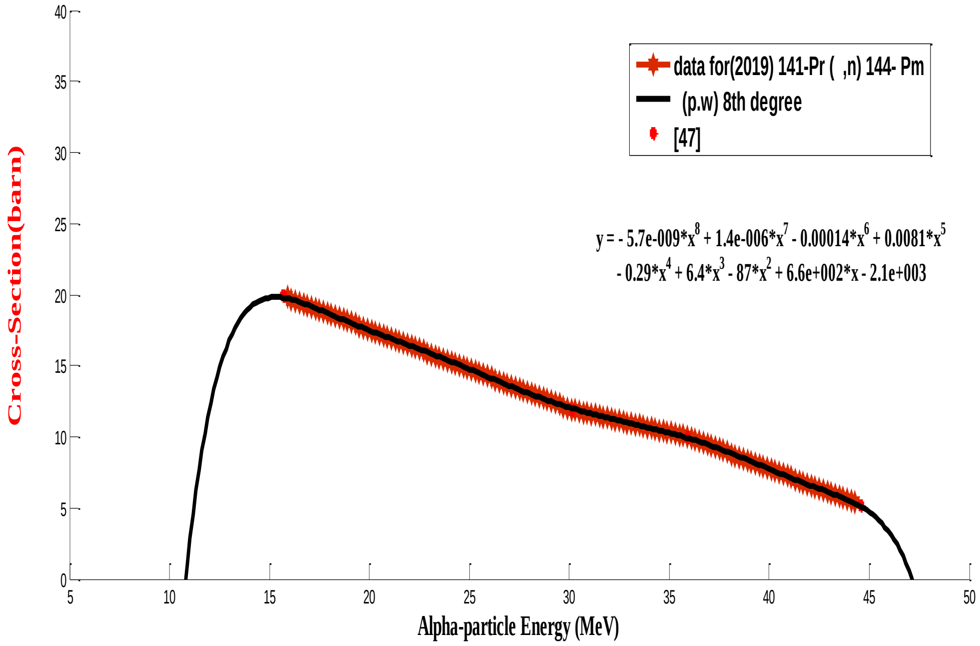


Fig.(3-2) The cross sections of $^{141}_{59}Pr(\alpha, n)\ ^{144}_{61}Pm$ reaction by fitting and interpolation(p.w).

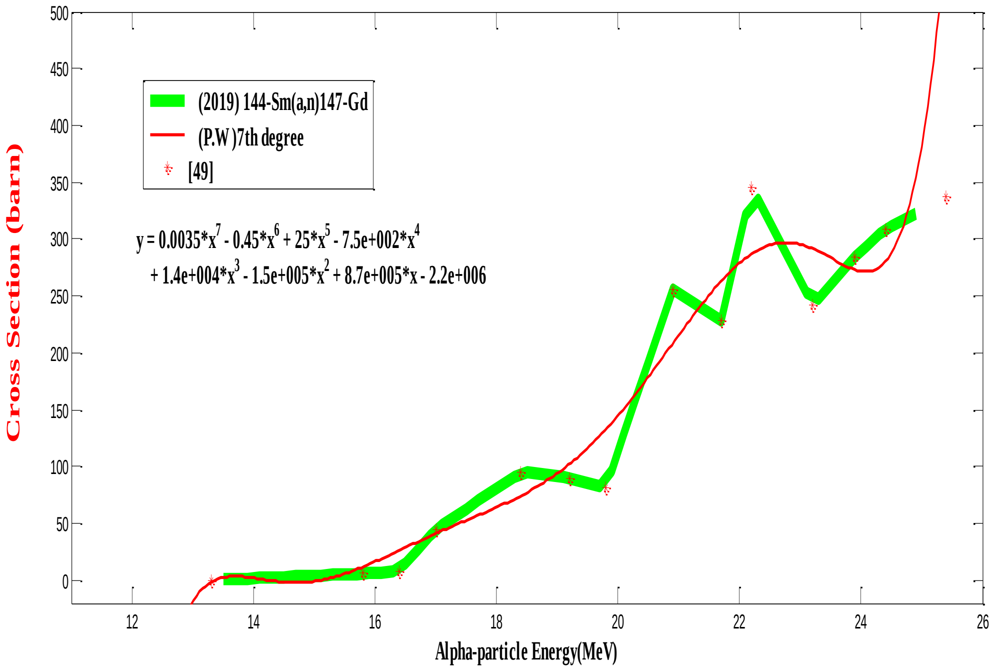


Fig.(3-3) The cross sections of $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ reaction by fitting and interpolation(p.w).

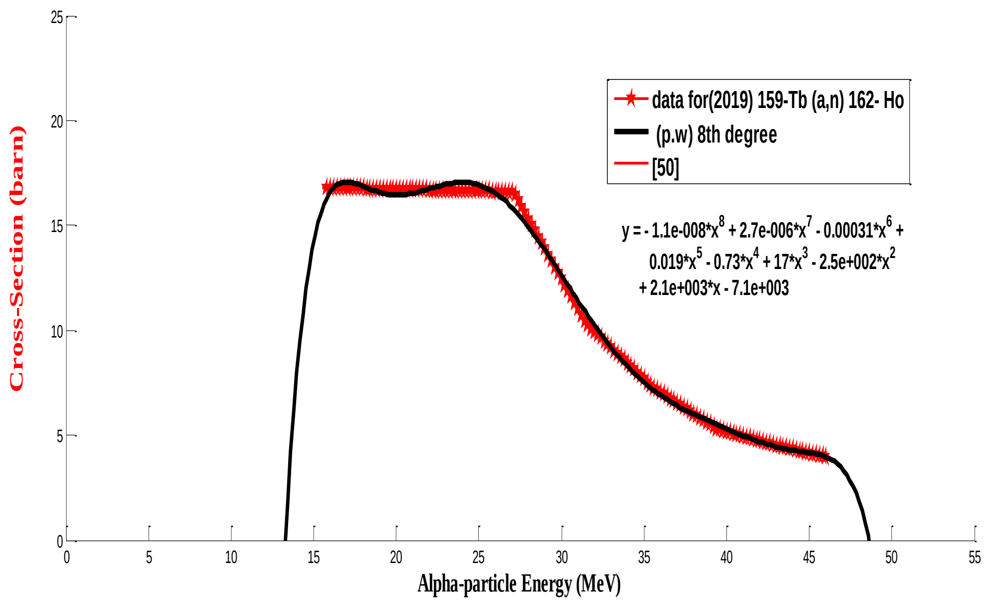


Fig.(3-4) The cross sections of $^{159}_{65}Tb(\alpha,n)^{162}_{67}Ho$ reaction by fitting and interpolation(p.w).

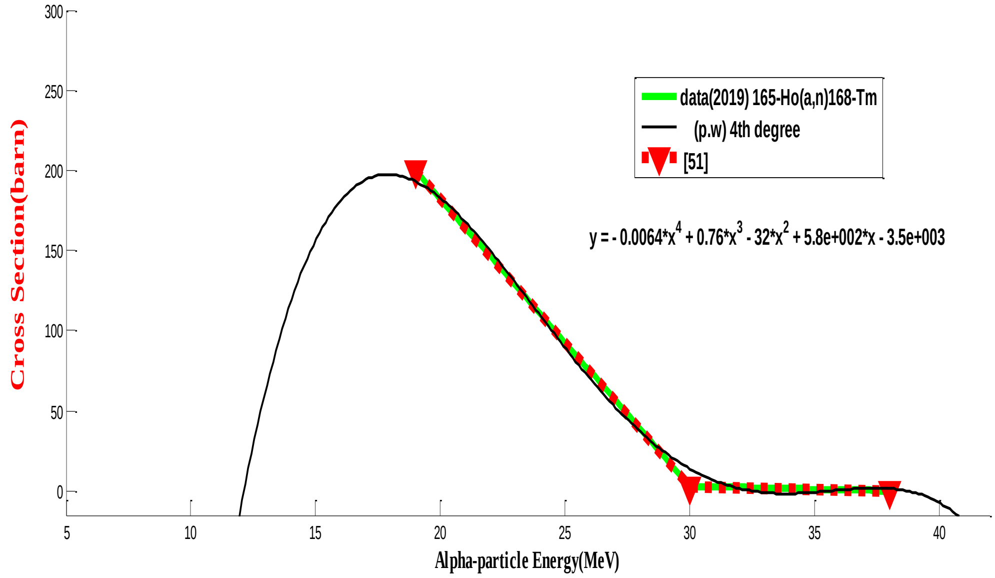


Fig.(3-5) The cross sections of ${}^{165}_{67}\mathrm{H0}(\alpha,\mathrm{n})\ {}^{168}_{69}\mathrm{Tm}$ reaction fitting and interpolation (p.w).

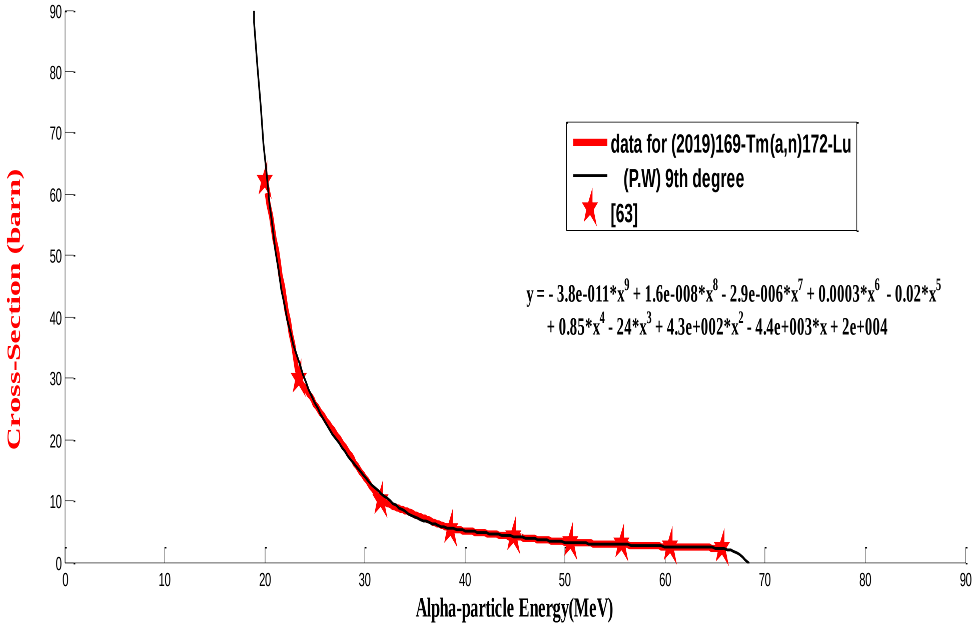


Fig.(3-6) The cross sections of ${}^{169}_{69}\mathrm{Tm}(\alpha,\mathrm{n}){}^{172}_{70}\mathrm{Lu}$ reaction by fitting and interpolation(p.w).

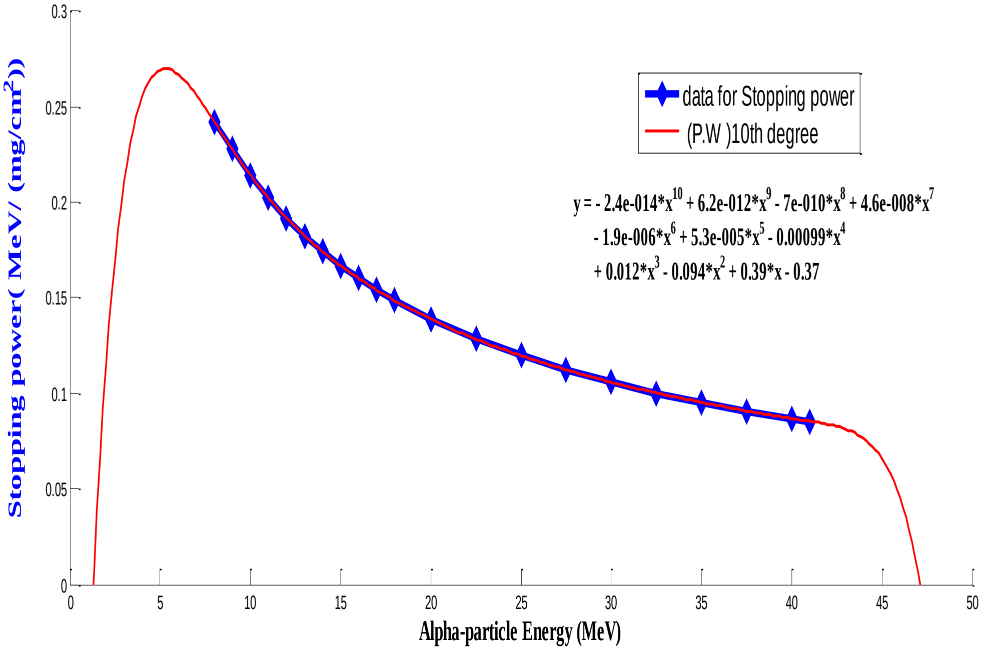


Fig.(3-7) The stopping power for $^{139}_{57}$La (α,n) $^{142}_{59}$Pr reaction(p.w).

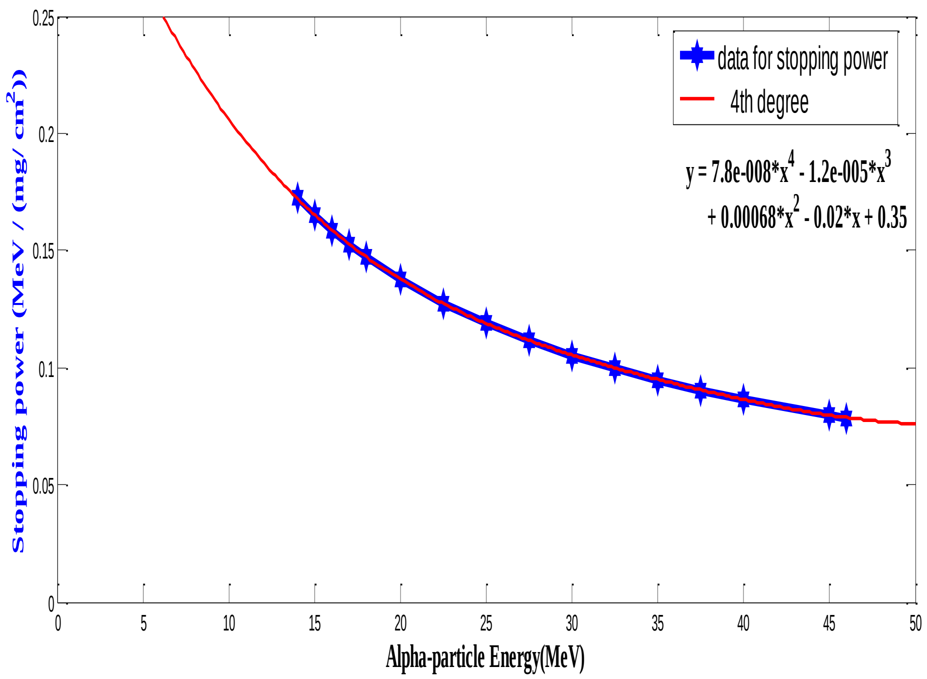


Fig.(3-8) The stopping power for $^{141}_{59}$Pr (α,n) $^{144}_{61}$Pm reaction (p.w).

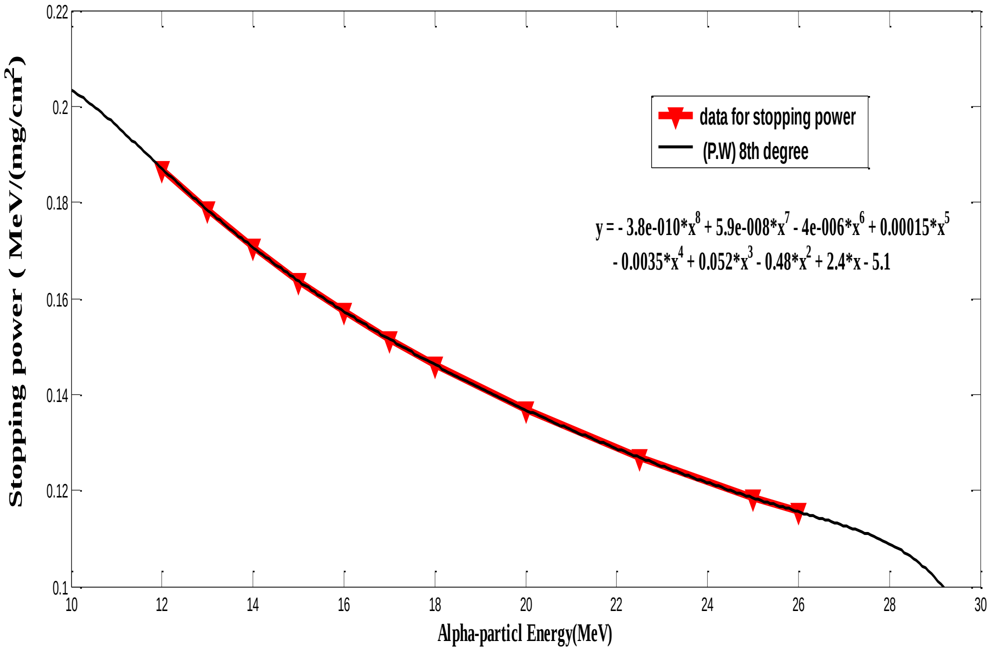


Fig.(3- 9) The stopping power for $^{144}_{62}Sm(\alpha, n)^{147}_{64}Gd$ reaction (p.w).

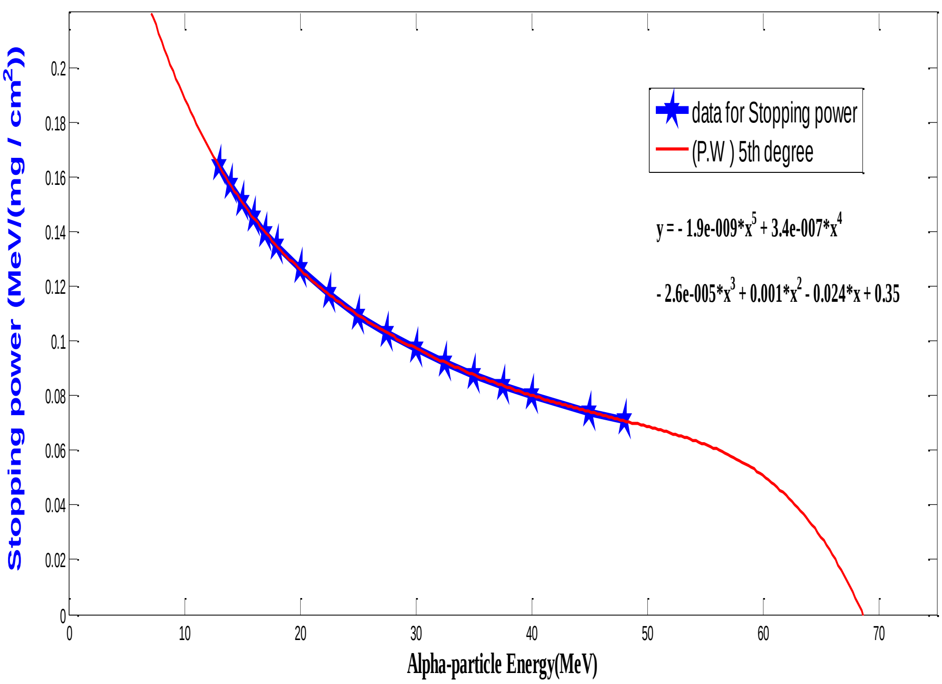


Fig. (3-10) The stopping power for $^{159}_{65}Tb(\alpha, n)^{162}_{67}Ho$ reaction (p.w)

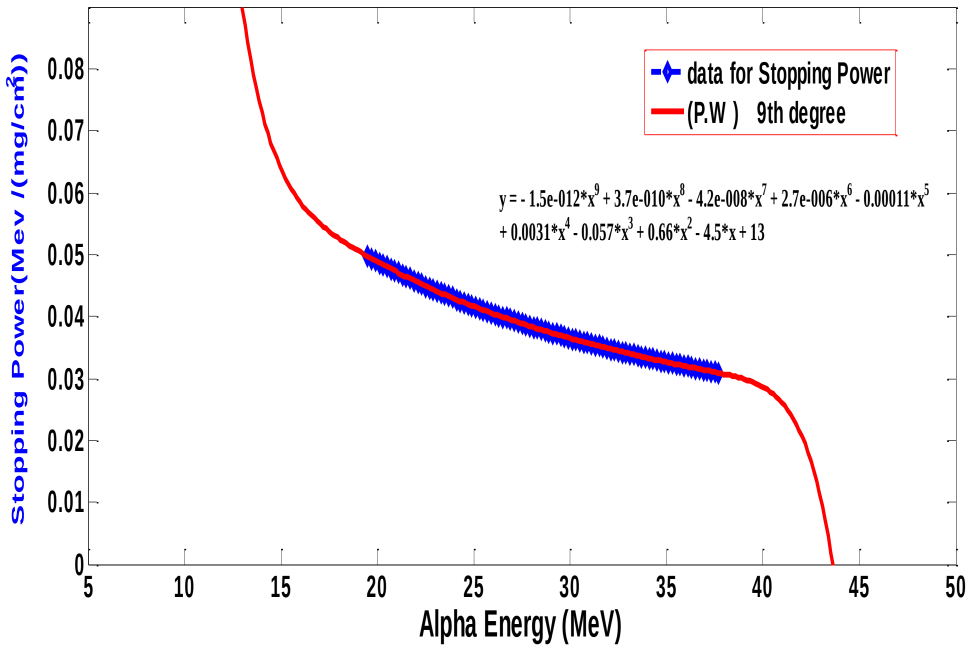


fig.(3-11) The stopping power for $^{165}_{67}$HO(α, n) $^{168}_{69}$Tm interaction (p.w).

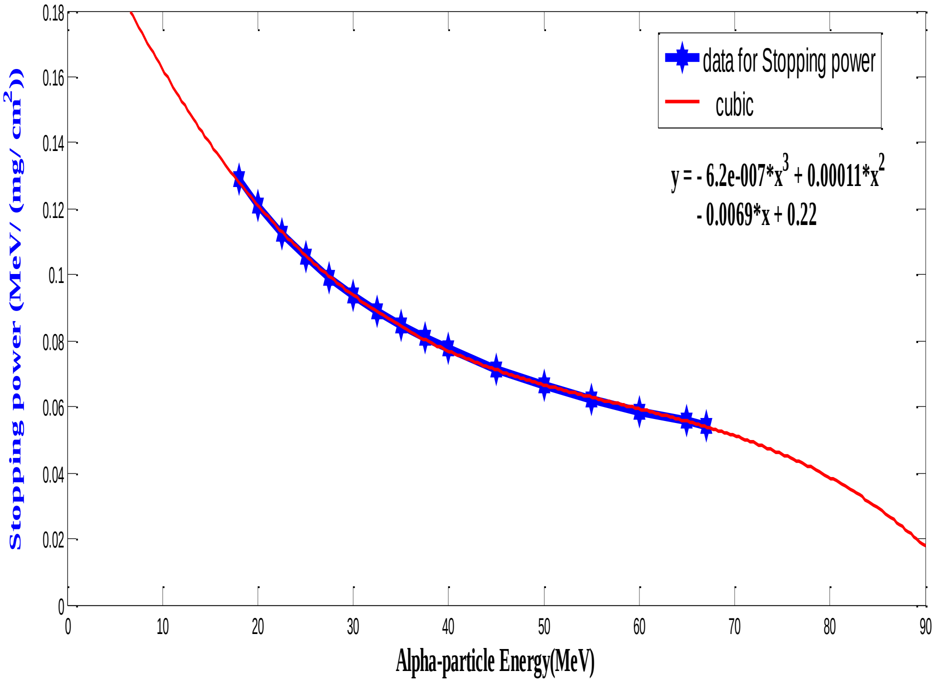


fig.(3-12) The stopping power for $^{169}_{69}$Tm$(\alpha, n)$$^{172}_{71}$Lu interaction(p.w).

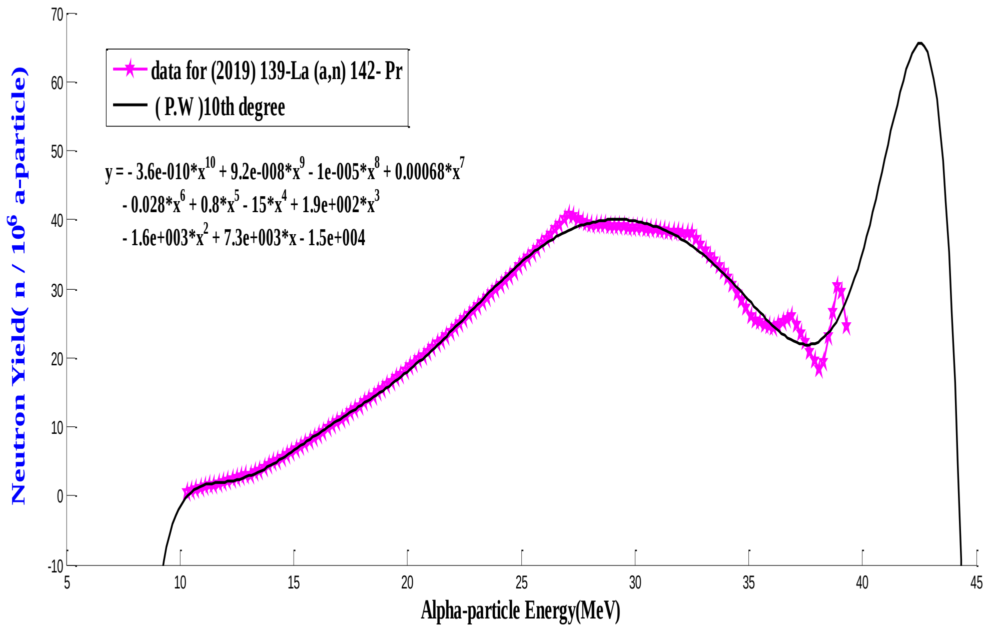


fig (3-13) The Neutron Yield for ${}^{139}_{57}\mathrm{La}\ (\alpha, n)\,{}^{142}_{59}\mathrm{Pr}$ interaction (p.w) .

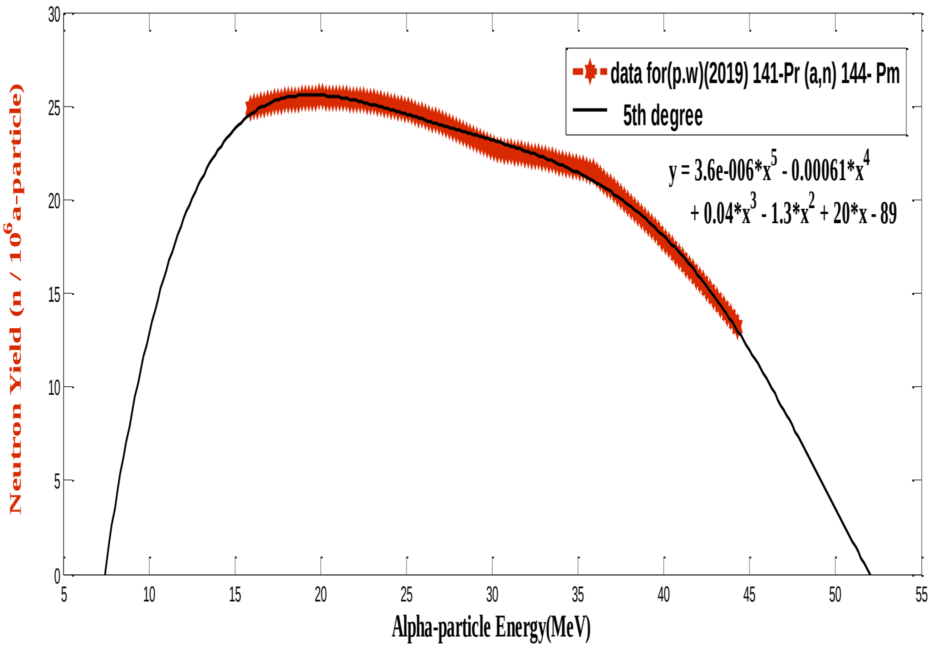


fig.(3-14) The Neutron Yield for ${}^{141}_{59}\mathrm{Pr}\ (\alpha, n)\,{}^{144}_{61}\mathrm{Pm}$ interaction (p.w).

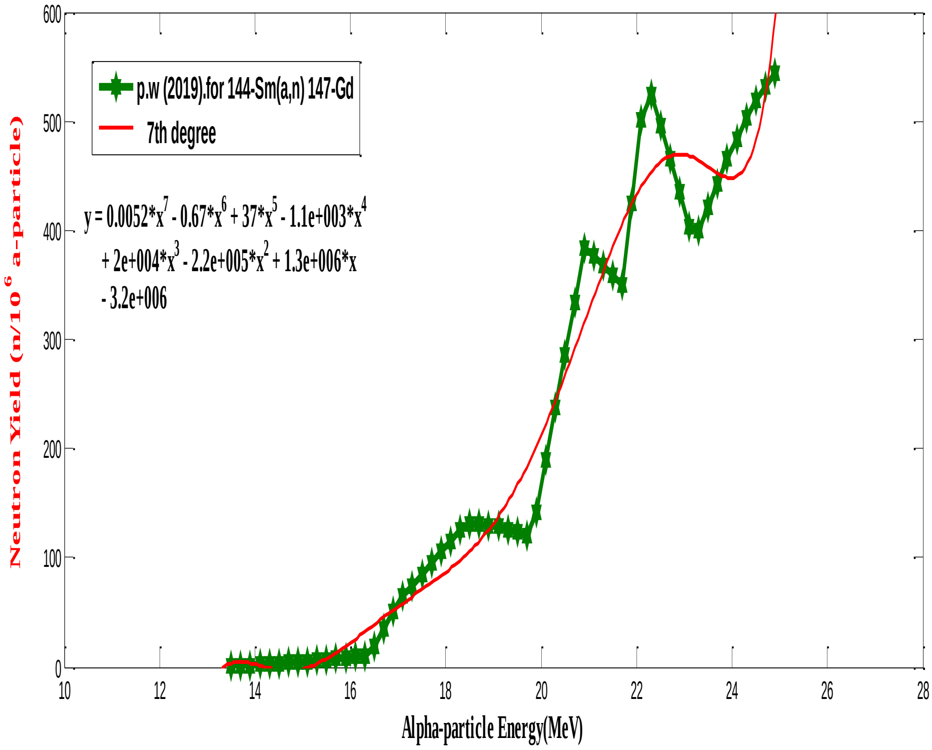


fig.(3 -15) The Neutron Yield for $^{144}_{62}\mathrm{Sm}(\alpha,n)^{147}_{64}\mathrm{Gd}$ interaction (p.w).

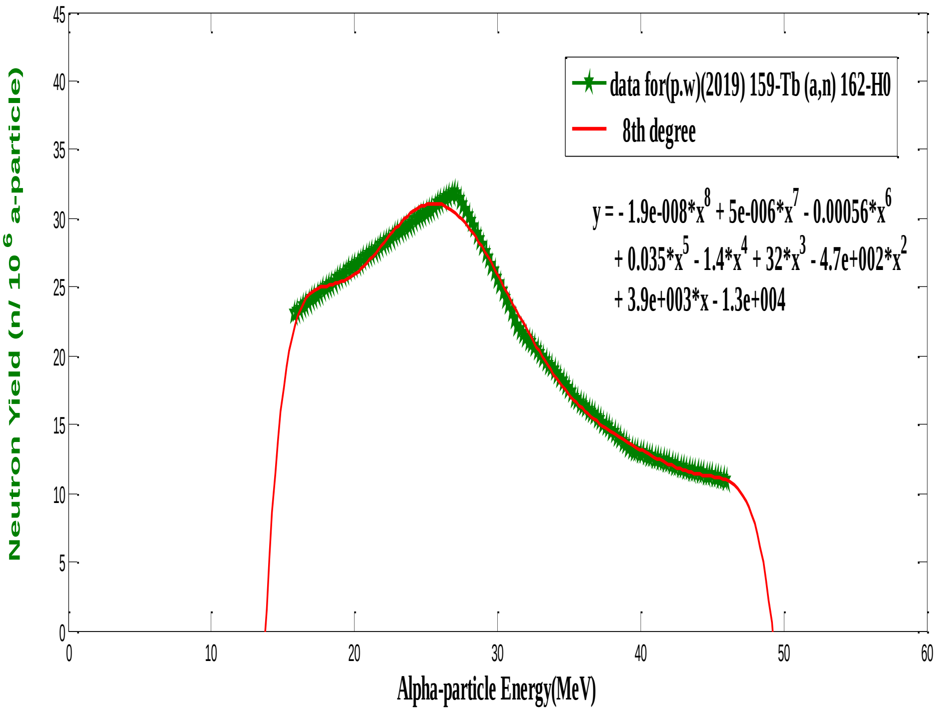


fig.(3 -16) The Neutron Yield for $^{159}_{65}\mathrm{Tb}(\alpha,n)^{162}_{67}\mathrm{Ho}$ interaction (p.w).

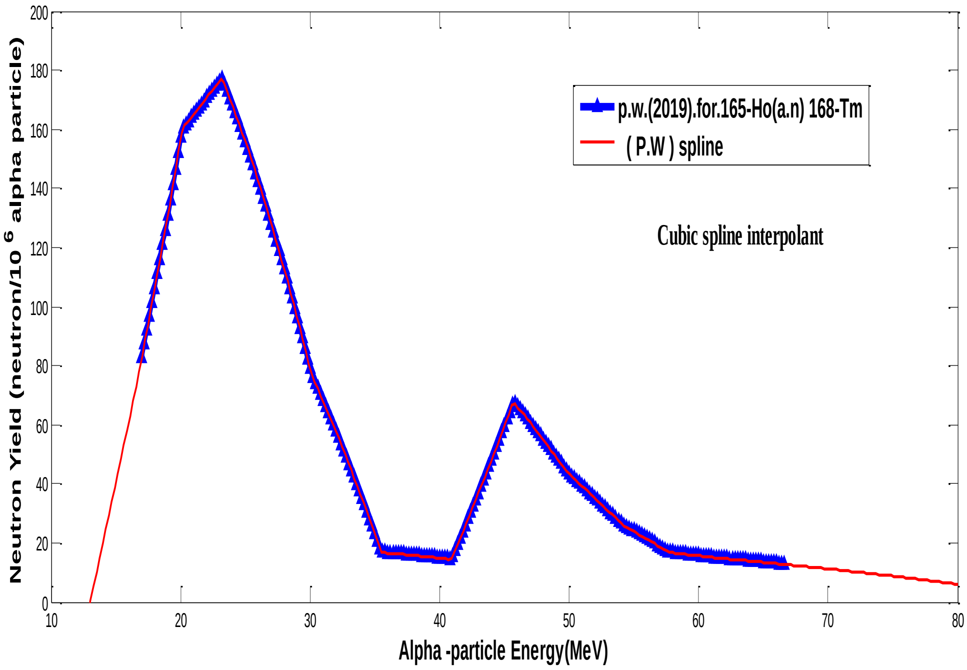


fig.(3- 17) The Neutron Yield for $^{165}_{67}$H0(α, n) $^{168}_{69}$Tm interaction (p.w).

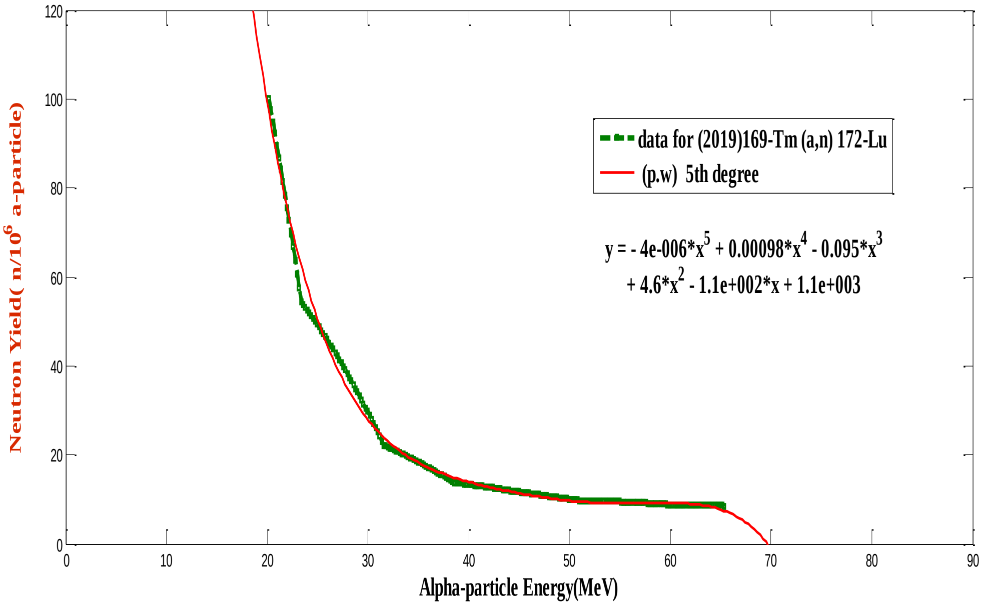


fig.(3 -18)The Neutron Yield for $^{169}_{69}$Tm(α, n) $^{172}_{71}$Lu interaction (p.w).

(3-8) The reciprocal cross sections of (α,n) reactions :

The evaluated cross sections of (n,α) reactions for target light isotopes ($^{139}_{57}\mathbf{La}$, $^{144}_{61}\mathbf{Pm}$, $^{147}_{64}\mathbf{Gd}$, $^{162}_{67}\mathbf{Ho}$, $^{168}_{69}\mathbf{Tm}$, $^{172}_{71}\mathbf{Lu}$) are calculated using reciprocity theory. The cross sections as a function of neutron energy are listed in the tables (3-10) to (3-15) and plotted in figs.(3-19) to (3-24) .Then we applied the reciprocity theory of reaction to get the semi empirical formula for the reactions in eq.(2-49).

Depending on parity and spin of isotopes in the ground state which is given in table (3-1), are calculation the g-statistical factor for every reaction using eq.(2-33) and (2-34). From table (3-1) and (3-2), we got atomic mass, $Q_{o\text{-value}}$, and threshold energy, then we calculate the kinetic energy of neutron using eq.(2-49).

(3-8-1) The cross sections of $^{142}_{59}\mathbf{Pr}(\mathbf{n},\boldsymbol{\alpha})\ ^{139}_{57}\mathbf{La}$ reaction:

The cross sections of $^{142}_{59}\mathbf{Pr}\,(\mathbf{n},\boldsymbol{\alpha})\ ^{139}_{57}\mathbf{La}$ reaction for neutron energy (0.089 to 26.63) MeV, were calculated using the reciprocity theory eq.(2- 49) as follows:

$$\sigma_{n,\alpha} = 1.587288\frac{T_\alpha}{T_n}\sigma_{\alpha,n} \quad \text{..,………...……..(3-18)}$$

From eq.(2-33) and (2-34) we get on the value of , $g_{\alpha,n}$= 1 and $g_{n,\alpha}$= $2/5$. The evaluations of cross sections are listed in the table (3-10) and plotted in fig.(3-19) also we got a semi -empirical formula of (10^{th}) degree by using computer program (MATLAB 7.6 R2008a).

Table (3-10) The cross sections for $^{142}_{59}Pr\ (n,\alpha)\,^{139}_{57}La$ reaction as a function of neutron energy (P.W) :

Neutron of Energy (MeV)	Cross sections of Neutron (barn) (P.W)	Neutron of Energy (MeV)	Cross sections of Neutron (barn)(P.W)
0.089	7.996	7.643	37.331
0.293	8.789	7.847	38.124
0.498	9.582	8.051	38.917
0.702	10.375	8.254	39.710
0.906	11.168	8.460	40.503
1.110	11.960	8.664	41.295
1.314	12.753	8.868	42.088
1.518	13.546	9.072	42.881
1.722	14.339	9.276	43.674
1.927	15.132	9.484	44.467
2.131	15.925	9.685	45.260
2.335	16.717	9.889	46.052
2.539	17.510	10.093	46.845
2.743	18.303	10.298	47.638
2.947	19.096	10.502	48.431
3.152	19.889	10.706	49.224
3.356	20.682	10.911	50.017
3.560	21.475	11.114	50.81
3.764	22.267	11.318	51.602
3.968	23.060	11.523	52.395
4.172	23.853	11.727	53.188
4.377	24.646	11.931	53.981
4.581	25.439	12.135	54.774
4.785	26.232	12.339	55.567
4.989	27.024	12.543	56.359
5.193	27.817	12.748	57.152
5.397	28.615	12.952	57.945
5.601	29.403	13.156	58.738
5.806	30.196	13.367	59.531
6.010	30.989	13.564	60.324
6.214	31.781	13.768	61.116
6.418	32.574	13.972	61.909
6.622	33.367	14.177	62.702
6.826	34.160	14.381	61.888
7.031	34.953	14.585	61.073
7.235	35.745	14.789	60.259
7.439	36.538	14.993	59.445

Table(3-10) Continued :

Neutron of Energy (MeV) (P.W)	Cross sections of Neutron (barn) (P.W)	Neutron of Energy (MeV) (P.W)	Cross sections of Neutron (barn) (P.W)
15.197	59.099	21.118	42.785
15.402	58.754	21.322	41.530
15.606	58.408	21.526	39.951
15.810	58.063	21.731	38.371
16.014	57.717	21.935	36.792
16.218	57.374	22.139	35.213
16.422	57.033	22.343	33.633
16.627	56.692	22.547	32.602
16.831	56.350	22.751	32.120
17.035	56.009	22.955	31.637
17.239	55.668	23.167	31.155
17.443	55.327	23.364	30.672
17.647	54.985	23.568	31.078
17.851	54.644	23.772	31.487
18.056	54.303	23.976	31.894
18.265	53.962	24.187	32.301
18.464	53.620	24.385	30.630
18.668	53.279	24.589	28.960
18.872	52.938	24.793	27.290
19.076	52.597	24.997	25.619
19.281	52.256	25.201	23.949
19.485	51.914	25.405	22.278
19.689	51.573	25.614	23.581
19.893	50.318	25.814	27.856
20.097	49.062	26.018	32.131
20.301	47.807	26.222	36.406
20.506	46.551	26.426	35.422
20.710	45.296	26.635	29.179
20.914	44.041	…….	…….

(3-8-2) The cross sections of ${}^{146}_{61}\mathrm{Pm}\ (\mathrm{n},\alpha)\,{}^{141}_{59}\mathrm{Pr}$ reaction :

The cross sections of ${}^{146}_{61}\mathbf{P}\boldsymbol{m}\ (\boldsymbol{n},\boldsymbol{\alpha})\,{}^{141}_{59}\boldsymbol{Pr}$ reaction for neutron energy (11.3 to 14.5) MeV, were calculated using the reciprocity theory eq.(2-50) as follows:

$$\sigma_{n,\alpha} = 0.270560\,\frac{T_\alpha}{T_n}\,\sigma_{\alpha,n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}19)$$

From eq.(2-33) and (2-34) we get on the value of , $g_{\alpha,n}$= 1 and $g_{n,\alpha}$= 6/88 . The evaluations of cross sections are listed in table (3-11) and plotted in fig.(3-20), also we got a semi- empirical formula of cubic spline interplant degree using a computer program (MATLAB 7.6 R 2008a).

Table (3-11) The cross sections of ${}^{144}_{61}\mathrm{Pm}(\mathrm{n},\alpha)\,{}^{141}_{59}\mathrm{Pr}$ reaction as a function for neutron energy (p.w) :

Energy of neutron MeV(p.w)	Cross Section (barn) (p.w)	Energy of neutron MeV(p.w)	Cross Section (barn) (p.w)
11.3	0.014	13.1	1.207
11.5	0.033	13.3	1.953
11.7	0.051	13.5	2.699
11.9	0.070	13.7	3.445
12.1	0.146	13.9	5.348
12.3	0.223	14.1	7.504
12.5	0.299	14.3	9.661
12.7	0.583	14.5	13.151
12.9	0.893	…..	……

(3-8-3) The cross sections of $^{147}_{64}\mathrm{Gd}(n,\alpha)^{144}_{62}\mathrm{Sm}$ reaction :

The cross sections of $^{147}_{64}\mathbf{Gd}(\mathbf{n},\boldsymbol{\alpha})^{144}_{62}\mathbf{Sm}$ reaction for neutron energy (0.8 – 12.2) MeV, were calculated using the reciprocity theory eq.(2-50) as follows:

$$\sigma_{n,\alpha} = 0.062003\frac{T_\alpha}{T_n}\sigma_{\alpha,n} \quad \text{........................(3-20)}$$

From eq.(2-33) and (2-34) we get on the value of , $g_{\alpha,n}$=1 and $g_{n,\alpha}$= $1/64$. The evaluations of cross sections are listed in the table (3-12) and plotted in fig.(3-21), also we got a semi - empirical formula of (5^{th}) degree using a computer program (MATLAB 7.6 R2008a).

Table (3-12) The cross sections of $^{147}_{64}\mathrm{Gd}(n,\alpha)^{144}_{62}\mathrm{Sm}$ reaction as a function for neutron energy (P.W) :

Energy of neutron MeV(P.W)	Cross Section(barn) (P.W)	Energy of neutron MeV(P.W)	Cross Section(barn) (P.W)	Energy of neutron MeV(P.W)	Cross Section(barn) (P.W)
0.8	0.043	4.6	8.334	8.4	37.124
1.0	0.116	4.8	9.431	8.6	36.048
1.2	0.197	5.0	10.529	8.8	34.972
1.4	0.263	5.2	11.627	9.0	37.195
1.6	0.337	5.4	12.725	9.2	44.388
1.8	0.410	5.6	13.822	9.4	51.580
2.0	0.484	5.8	14.194	9.6	48.932
2.2	0.557	6.0	14.002	9.8	45.766
2.4	0.631	6.2	13.810	10.0	42.600
2.6	0.704	6.4	13.618	10.2	39.434
2.8	0.778	6.6	13.252	10.4	36.529
3.0	0.851	6.8	12.791	10.6	38.373
3.2	0.933	7.0	12.330	10.8	40.218
3.4	1.036	7.2	15.644	11.0	42.062
3.6	1.138	7.4	20.534	11.2	43.715
3.8	1.884	7.6	25.424	11.4	45.251
4.0	3.780	7.8	30.314	11.6	46.670
4.2	5.676	8.0	35.204	11.8	47.531
4.4	7.236	8.2	38.199	12.0	48.392
....	....	......	....	12.2	49.252

(3-8-4) The cross sections of $^{162}_{67}\mathrm{Ho}\ (\mathrm{n},\alpha)\ ^{159}_{65}\mathrm{Tb}$ reaction :

The cross sections for $^{162}_{67}\mathbf{Ho}(\mathbf{n},\boldsymbol{\alpha})^{159}_{65}\mathbf{Tb}$ reaction of neutron energy (6.1 to 36.1) MeV, were calculated using the reciprocity theory eq.(2-50) as follows:

$$\sigma_{n,\alpha} = 4.629592\,\frac{M_\alpha T_\alpha}{M_n T_n}\,\sigma_{\alpha,n} \quad \text{.........................(3-21)}$$

From eq.(2-33) and (2-34) we get on the value , $g_{\alpha,n} = 2/7$ and $g_{n,\alpha} = 1/3$. The evaluations of cross sections are listed in the table (3-13) and plotted in fig.(3-22) also we got a semi - empirical formula of (8th) degree by using a computer program (MATLAB 7.6 R2008a).

Table (3-13) The cross sections of $^{162}_{67}\mathrm{Ho}(\mathrm{n},\alpha)^{159}_{65}\mathrm{Tb}$ reaction as a function for neutron energy (p.w):

Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)
6.1	105.261	10.9	104.732	20.5	75.718	25.3	47.412
6.3	105.238	11.1	104.716	20.7	73.890	25.5	46.453
6.5	105.216	11.3	104.688	20.9	72.062	25.7	45.57
6.7	105.194	11.5	104.666	21.1	70.234	25.9	44.920
6.9	105.172	11.7	104.644	21.3	68.406	26.1	44.265
7.1	105.150	11.9	104.622	21.5	66.578	26.3	43.610
7.3	105.128	12.1	104.600	21.7	64.749	26.5	42.955
7.5	105.106	12.3	104.578	21.9	63.692	26.7	42.301
7.7	105.084	12.5	104.556	22.1	62.734	26.9	41.646
7.9	105.062	12.7	104.534	22.3	61.777	27.1	40.991
8.1	105.040	12.9	104.512	22.5	60.819	27.3	40.336
8.3	105.018	13.1	104.490	22.7	59.862	27.5	39.682
8.5	104.996	13.3	104.468	22.9	58.904	27.7	39.027
8.7	104.974	13.5	104.446	23.1	57.946	27.9	38.372
8.9	104.952	13.7	104.424	23.3	56.989	28.1	37.717
9.1	104.930	18.7	92.172	23.5	56.031	28.3	37.062
9.3	104.908	18.9	90.344	23.7	55.073	28.5	36.408
9.5	104.886	19.1	88.515	23.9	54.116	28.7	35.753
9.7	104.864	19.3	86.687	24.1	53.158	28.9	35.098
9.9	104.842	19.5	84.859	24.3	52.201	29.1	34.443
10.1	104.820	19.7	83.031	24.5	51.243	29.3	33.788
10.3	104.798	19.9	81.203	24.7	50.285	29.5	33.177
10.5	104.776	20.1	79.375	24.9	49.328	29.7	32.893
10.7	104.754	20.3	77.546	25.1	48.370	29.9	32.609

Table(3-13) Continued :

Energy neutron (MeV)(p.w)	Cross Section (barn) (p.w)	Energy neutron (MeV)(p.w)	Cross Section (barn) (p.w)	Energy neutron (MeV)(p.w)	Cross Section (barn) (p.w)
30.1	32.326	32.9	28.353	35.7	25.167
30.3	32.042	33.1	28.091	35.9	24.941
30.5	31.758	33.3	27.870	36.1	24.716
30.7	31.474	33.5	27.645	…..	……
30.9	31.191	33.7	27.420		
31.1	30.907	33.9	27.194		
31.3	30.623	34.1	26.969		
31.5	30.339	34.3	26.744		
31.7	30.056	34.5	26.518		
31.9	29.772	34.7	26.293		
32.1	29.488	34.9	26.068		
32.3	29.204	35.1	25.842		
32.5	28.921	35.3	25.617		

(3-8-5) The cross sections of $^{168}_{69}\mathrm{Tm}(\mathrm{n},\alpha)^{165}_{67}\mathrm{Ho}$ reaction :

The cross sections of $^{168}_{69}\mathbf{Tm}(\mathbf{n},\boldsymbol{\alpha})^{165}_{67}\mathbf{Ho}$ reaction neutron energy (9.5 to 27.9) MeV, were calculated using the reciprocity theory eq. (2-50) as follows: $\sigma_{n,\alpha} = 5.29096\,\frac{T_\alpha}{T_n}\,\sigma_{\alpha,n}$ ....(3-22)

From eq.(2-33) and (2- 34) we get on the value of , $g_{\alpha,n}= 1/28$ and $g_{n,\alpha}= 1/21$. The evaluations of cross sections are listed in the table (3-14) and plotted in fig.(3-23), also we got a semi- empirical formula of (4^{th}) degree by using a computer program (MATLAB 7.6 R2008a).

Table (3-14) The cross sections of $^{168}_{69}\mathrm{Tm}(\mathrm{n},\alpha)^{165}_{67}\mathrm{Ho}$ reaction as a function for neutron energy (p.w):

Energy neutron MeV	Cross Section (barn)	Energy neutron MeV	Cross Section (barn)	Energy neutron MeV	Cross Section (barn)	Energy neutron MeV	Cross Section (barn)
9.5	1.509	14.3	0.841	19.1	0.172	23.9	0.012
9.7	1.481	14.5	0.813	19.3	0.145	24.1	0.011
9.9	1.453	14.7	0.785	19.5	0.117	24.3	0.011
10.1	1.426	14.9	0.757	19.7	0.089	24.5	0.010
10.3	1.398	15.1	0.729	19.9	0.061	24.7	0.010
10.5	1.370	15.3	0.702	20.1	0.033	24.9	0.009
10.7	1.342	15.5	0.674	20.3	0.022	25.1	0.009
10.9	1.314	15.7	0.646	20.5	0.022	25.3	0.008
11.1	1.286	15.9	0.618	20.7	0.021	25.5	0.007
11.3	1.259	16.1	0.590	20.9	0.020	25.7	0.007
11.5	1.231	16.3	0.562	21.1	0.020	25.9	0.006
11.7	1.203	16.5	0.534	21.3	0.019	26.1	0.006
11.9	1.175	16.7	0.507	21.5	0.019	26.3	0.005
12.1	1.147	16.9	0.479	21.7	0.018	26.5	0.005
12.3	1.119	17.1	0.451	21.9	0.018	26.7	0.004
12.5	1.091	17.3	0.423	22.1	0.017	26.9	0.004
12.7	1.064	17.5	0.395	22.3	0.016	27.1	0.003
12.9	1.036	17.7	0.367	22.5	0.016	27.3	0.002
13.1	1.008	17.9	0.339	22.7	0.015	27.5	0.002
13.3	0.980	18.1	0.312	22.9	0.015	27.7	0.001
13.5	0.952	18.3	0.284	23.1	0.014	27.9	0.001
13.7	0.924	18.5	0.256	23.3	0.014	….	…..
13.9	0.896	18.7	0.228	23.5	0.013	…..	…..
14.1	0.869	18.9	0.200	23.7	0.013	……	……

(3-8-6) The cross sections of ${}^{172}_{71}\mathrm{Lu}(\mathrm{n},\alpha){}^{169}_{69}\mathrm{Tm}$ reaction :

The cross sections for ${}^{172}_{71}\mathrm{Lu}(\mathrm{n},\alpha){}^{169}_{69}\mathrm{Tm}$ reaction of neutron energy (9.5 to 54.1) MeV, were calculated using the reciprocity theory eq.(2-50) as follows:

$$\sigma_{n,\alpha} = 1.984111 \frac{T_\alpha}{T_n} \sigma_{\alpha,n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}23)$$

From eq.(2-33) and (2-34) we get on the value , $g_{\alpha,n}= 4/9$ and $g_{n,\alpha}= 2/9$ The evaluations of cross sections are listed in table (3-15) and plotted in fig.(3-24),also we got a semi - empirical formula of (7^{th}) degree using a computer program (MATLAB version 7.6 R2008a).

Table (3-15): The cross sections of ${}^{172}_{71}\mathrm{Lu}(\mathrm{n},\alpha){}^{169}_{69}Tm$ reaction as a function for neutron energy (p.w) :

Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)
9.5	155.704	14.1	67.298	18.7	38.539	23.3	21.151
9.7	150.783	14.3	66.048	18.9	37.288	23.5	20.813
9.9	145.862	14.5	64.797	19.1	36.038	23.7	20.475
10.1	140.941	14.7	63.547	19.3	34.787	23.9	20.136
10.3	136.020	14.9	62.296	19.5	33.537	24.1	19.798
10.5	131.099	15.1	61.046	19.7	32.286	24.3	19.460
10.7	126.178	15.3	59.796	19.9	31.036	24.5	19.122
10.9	121.257	15.5	58.545	20.1	29.786	24.7	18.784
11.1	116.335	15.7	57.295	20.3	28.535	24.9	18.446
11.3	111.414	15.9	56.044	20.5	27.285	25.1	18.108
11.5	106.493	16.1	54.794	20.7	26.034	25.3	17.770
11.7	101.572	16.3	53.544	20.9	25.208	25.5	17.432
11.9	96.651	16.5	52.293	21.1	24.870	25.7	17.094
12.1	91.730	16.7	51.043	21.3	24.532	25.9	16.756
12.3	86.809	16.9	49.792	21.5	24.193	26.1	16.418
12.5	81.888	17.1	48.542	21.7	23.855	26.3	16.081
12.7	76.967	17.3	47.291	21.9	23.517	26.5	15.741
12.9	74.801	17.5	46.041	22.1	23.179	26.7	15.403
13.1	73.550	17.7	44.791	22.3	22.841	26.9	15.065
13.3	72.300	17.9	43.540	22.5	22.503	27.1	14.727
13.5	71.049	18.1	42.290	22.7	22.165	27.3	14.389
13.7	69.799	18.3	41.039	22.9	21.827	27.5	14.051
13.9	68.549	18.5	39.789	23.1	21.489	27.7	13.730

Table(3-15) Continued :

Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)	Energy neutron (MeV)	Cross Section (barn)
27.9	13.627	32.3	11.348	36.7	9.313	41.1	7.852
28.1	13.523	32.5	11.245	36.9	9.227	41.3	7.819
28.3	13.424	32.7	11.141	37.1	9.141	41.5	7.787
28.5	13.316	32.9	11.037	37.3	9.055	41.7	7.754
28.7	13.212	33.1	10.934	37.5	8.968	41.9	7.722
28.9	13.109	33.3	10.830	37.7	8.882	42.1	7.689
29.1	13.005	33.5	10.727	37.9	8.796	42.3	7.657
29.3	12.902	33.7	10.623	38.1	8.709	42.5	7.624
29.5	12.798	33.9	10.522	38.3	8.623	42.7	7.592
29.7	12.695	34.1	10.435	38.5	8.537	42.9	7.559
29.9	12.591	34.3	10.349	38.7	8.450	43.1	7.527
30.1	12.487	34.5	10.263	38.9	8.364	43.3	7.494
30.3	12.384	34.7	10.177	39.1	8.278	43.5	7.462
30.5	12.280	34.9	10.090	39.3	8.191	43.7	7.429
30.7	12.177	35.1	10.004	39.5	8.112	43.9	7.397
30.9	12.073	35.3	9.918	39.7	8.079	44.1	7.364
31.1	11.975	35.5	9.831	39.9	8.047	44.3	7.332
31.3	11.866	35.7	9.745	40.1	8.014	44.5	7.299
31.5	11.762	35.9	9.659	40.3	7.982	……	…….
31.7	11.659	36.1	9.572	40.5	7.949	………	…….
31.9	11.555	36.3	9.486	40.7	7.917	……..	……..
32.1	11.452	36.5	9.400	40.9	7.884	……..	…….

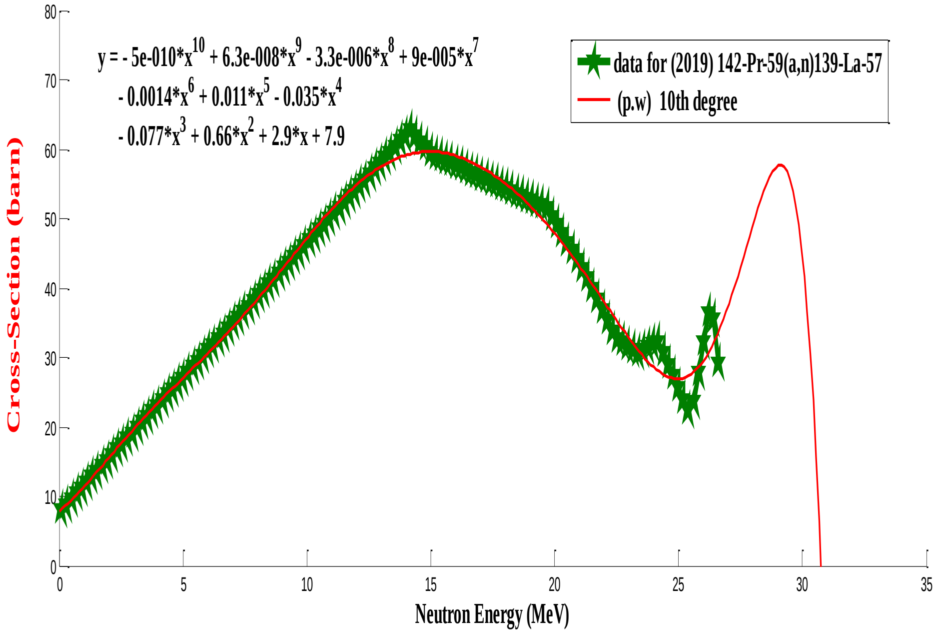
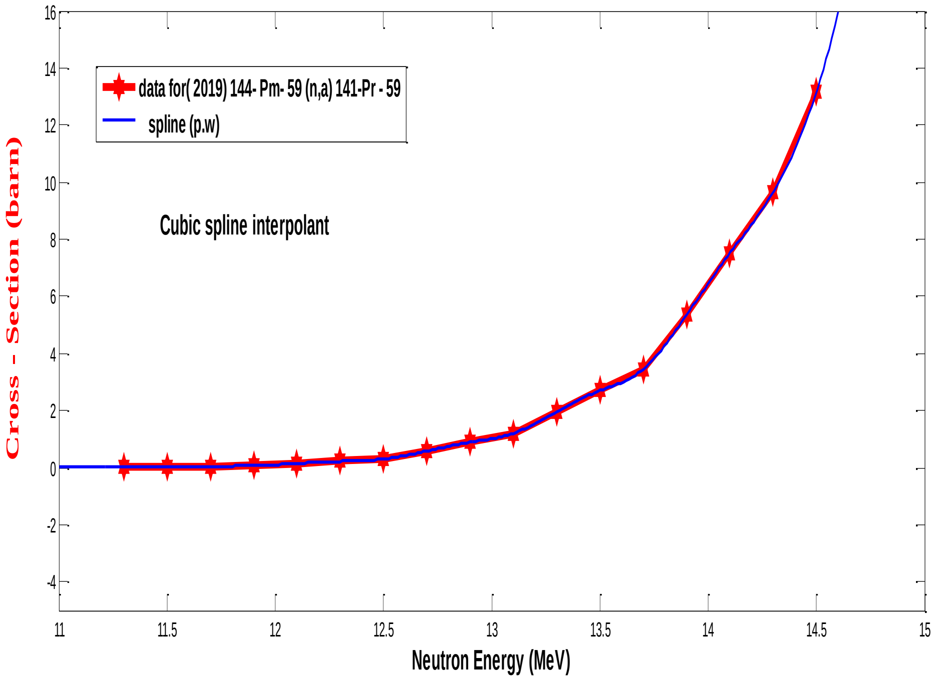


Fig.(3- 19) The cross section of $^{142}_{59}$Pr (n, α) $^{139}_{57}$La reaction(p.w).



Fig(3-20) The cross section of $^{144}_{61}$Pm (n, α) $^{141}_{59}$Pr reaction (p.w).

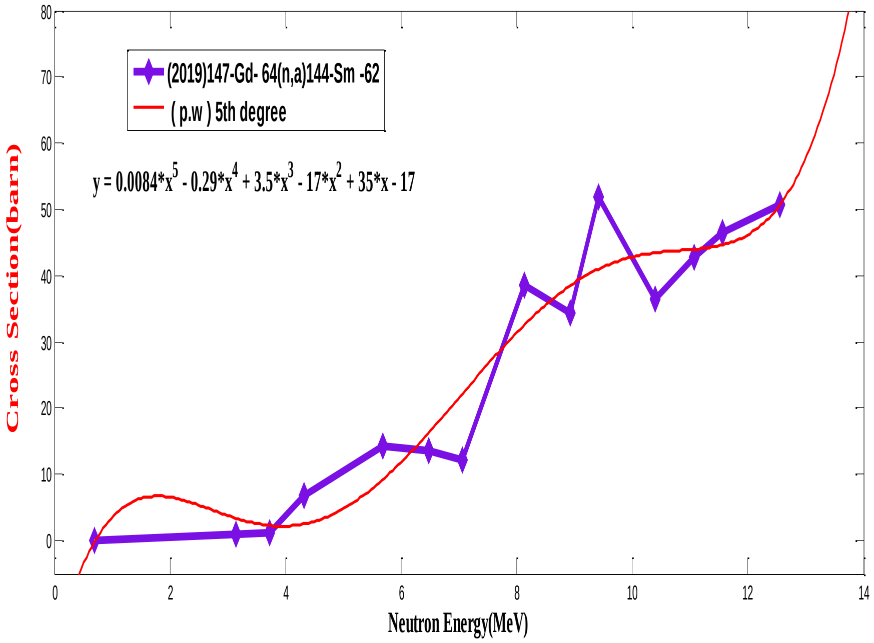


Fig. (3-21) The cross section of $^{147}_{64}\mathrm{Gd}(n,\alpha)^{144}_{62}\mathrm{Sm}$ reaction(p.w).

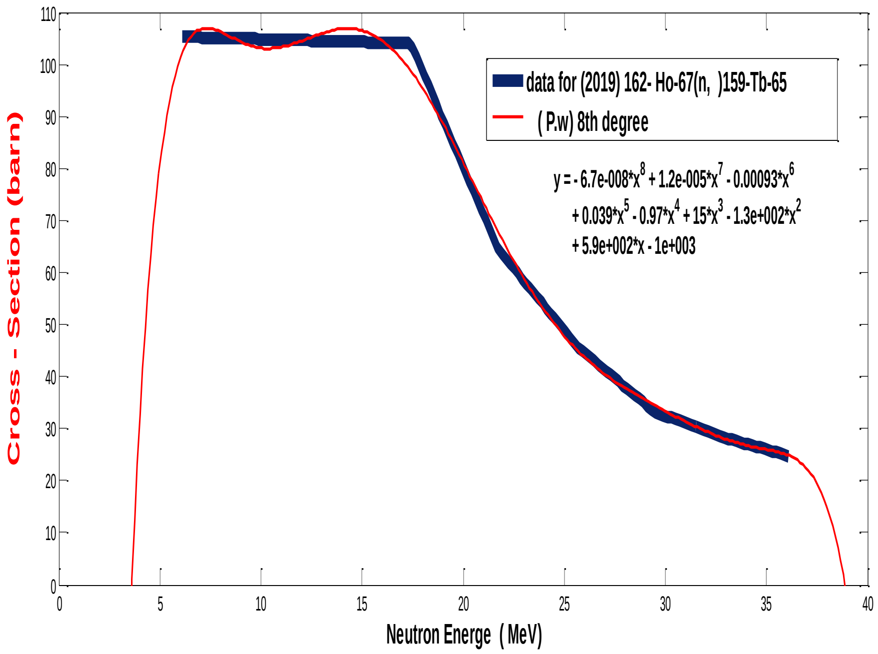


Fig.(3-22) The cross section of $^{162}_{67}\mathrm{Ho}(n,\alpha)^{159}_{65}\mathrm{Tb}$ reaction(p.w) .

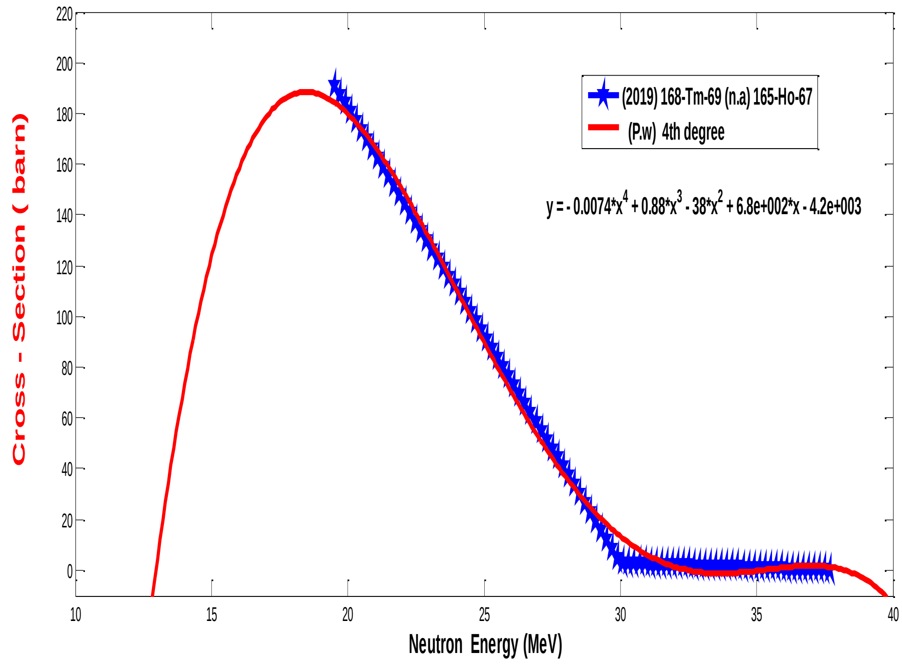


Fig.(3-23)The cross section of $^{168}_{69}\mathrm{Tm}(\mathrm{n},\alpha)^{165}_{67}\mathrm{Ho}$ reaction(p.w) .

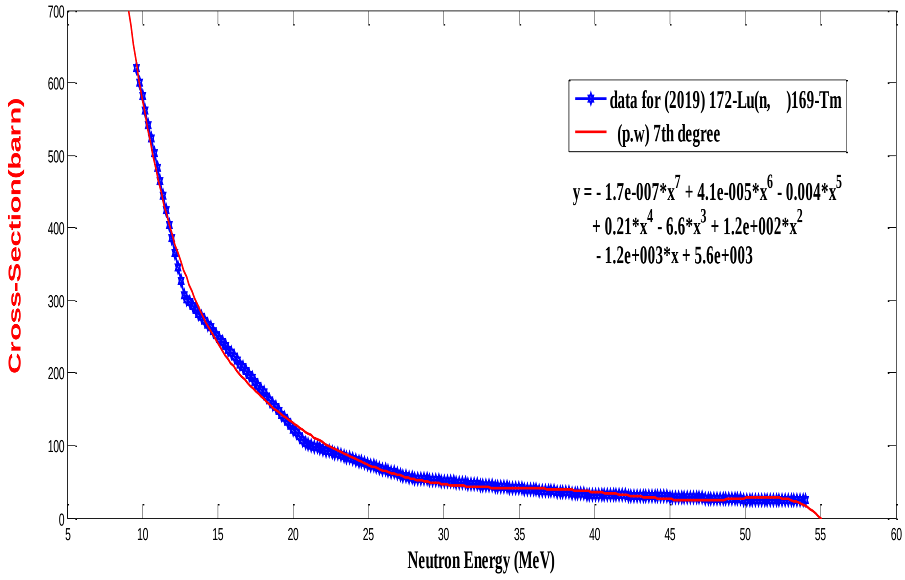


Fig.(3-24) The cross section of $^{172}_{71}\mathrm{Lu}(\mathrm{n},\alpha)$ $^{169}_{69}\mathrm{Tm}$ reaction (p.w).

Chapter Four
Discussion and Conclusion

Chapter Four

(4 -1) Basic properties for the nuclear reaction :

In the present study, our observations depend on some basic properties for nuclear reaction which are required for several purposes in comparison with the stability of the nucleus with another nucleus such as :

1- Mass excess and packing fraction have a negative value for each light element(as mentioned in table(3-1) from $^{139}_{57}La$ to $^{173}_{71}Lu$, also abundance, spin, parity ,and half-life of α-emitters .

2- The Q_o-value and threshold energy for (α ,n) reaction have been calculated as shown in the table (3-2) .

The (α ,n) reactions are endoergic reactions, they have negative value with the range (− 12.2538 MeV) for $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ to (− 9.0853MeV) for $^{139}_{57}La\,(\alpha,n)^{142}_{59}Pr$ and value of threshold with the range (9.3468 MeV) for $^{139}_{57}La\,(\alpha,n)^{142}_{59}Pr$ to (12.5942 MeV) for $^{144}_{62}Sm(\alpha,n)^{147}_{64}Gd$ in respectively.

3- The value of binding energy for any nuclide was easily calculated, from the difference in mass of nucleus and the sum of the masses of the number of free neutrons and protons that make up the nucleus with the range (1164.4914 MeV) for $^{139}_{57}La\,(\alpha,n)^{142}_{59}Pr$ reaction to (1371.2741 MeV) for $^{169}_{69}Tm(\alpha,n)^{172}_{71}Lu$ reaction.

4- The value of reduced mass also have been calculated as shown in table (3-2) with the range (3.8904) for $^{139}_{57}La\,(\alpha,n)^{142}_{59}Pr$ to(3.9099) for $^{169}_{69}Tm(\alpha,n)^{172}_{71}Lu$, and calculated the value of coulomb barrier with the range (20. 2142 MeV) for $^{139}_{57}La\,(\alpha,n)^{142}_{59}Pr$ to (23.2709 MeV) for $^{169}_{69}Tm(\alpha,n)^{172}_{71}Lu$ in the same table .

(4-2)The properties of nuclear cross-section reactions of (α,n):

(4-2-1) The ${}^{139}_{57}La\,(\alpha,n)\,{}^{142}_{59}Pr$ reaction:

From calculating of the cross section, stopping power and neutron yield of this reaction which has (odd–even) target nucleus ${}^{139}_{57}La_{82}$ as mentioned in chapter three in table (3-4) and fig.(3-1), it can be observed that the high probability to produce ${}^{142}_{59}Pr$ by bombard ${}^{139}_{57}La$ with alpha energy (27.1 MeV) is (23.1 barn), and less probability to produce ${}^{142}_{59}Pr$ by bombard ${}^{139}_{57}La$ with alpha energy (10.3 MeV) , is (0.499 barn).

Where the cross section as a function of neutron energy are increased in range from (10.3 to 27.1) MeV and decreased and increased one more time, that is deferent to previous reading of researchers.

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum cross sections for the inverse reactions was (26.70 barn) at neutron energy (14.17 MeV) ,and minimum inverse cross-section was(7.99 barn) at (0,089 MeV) as shown in the table (3-10),and in fig.(3-19), can be observed that inverse cross-section are increased when the energy is increased until it reaches the highest value and then decreases the neutron yield by increasing energy.

In fig.(3-7) in the same the table (3-4) when the alpha energy is (10.3MeV) the maximum of the stopping power is (0.210 MeV/ (mg/cm^2)) and the stopping power is decreased to the minimum value is(0.088 MeV/(mg/cm^2)) at energy (39.3 MeV).

in fig.(3-13) the maximum neutron yield is (40.689 n /10^6 $\alpha -$ particle) at (27.1MeV) for alpha energy ,and decreased to (0.473 n /10^6 $\alpha -$ particle) at (10.3 MeV) as shown in table (3-4) . Conclude that the high probability to produce ${}^{139}_{57}La$ is bombarded by ${}^{142}_{59}Pr$ with the fast neutron.

(4-2-2) The ${}^{141}_{59}\mathrm{Pr}\,(\alpha, n)\,{}^{144}_{61}\mathrm{Pm}$ reaction:

From calculating of the cross section, stopping power and neutron yield of this reaction which has (odd–even) target nucleus ${}^{141}_{59}\mathrm{Pr}_{82}$ with magic number of neutrons and it can be observed that the high probability to produce ${}^{144}_{61}\mathrm{Pm}$ by bombard ${}^{141}_{59}\mathrm{Pr}$ with alpha energy (15.9MeV) is (19.79 barn). Conclude the cross sections as a function of alpha energy are decreased when alpha energy is increased as shown in table (3-5) in fig.(3-2). and less probability to produce ${}^{144}_{61}\mathrm{Pm}$ by bombard ${}^{141}_{59}\mathrm{Pr}$ with alpha energy is increased (44.3 MeV) is (5.349 barn).

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum cross sections for the inverse reactions was (13.15 barn) at neutron energy (14.5 MeV) ,and minimum inverse cross-section was(0.014 barn) at (11.3 MeV) as shown in the table (3- 11),and in fig.(3-20). Conclude when increased neutron energy the inverse cross sections also increased.

In fig.(3-8), and the table (3-5) when the alpha energy is increased (15.9 MeV), the stopping power is (0.159 MeV/ (mg/cm^2)) until reached energy (44.3 MeV) the stopping power is decreased (0.080 MeV/ (mg/cm^2).

In fig.(3-14) the maximum neutron yield is (25.465 n /10^6 $\alpha -$ particle) at (20.1MeV) for alpha energy ,and decreased to (13.262 n /10^6 $\alpha -$ particle) at (44.3 MeV) as shown in table (3-5). Conclude that the high probability to produce ${}^{144}_{61}\mathrm{Pm}$ is bombarded by ${}^{141}_{59}\mathrm{Pr}$ with the neutron.

(4-2-3) The $^{144}_{62}\mathrm{Sm}\,(\alpha, n)\,^{147}_{64}\mathrm{Gd}$ reaction:

From the results of this study , it can be noticed that this reaction has (even – even) target nucleus $^{144}_{62}\mathrm{Sm}_{82}$ with magic number of neutrons and we observe that the high probability to produce $^{147}_{64}\mathrm{Gd}$ by bombard $^{144}_{62}\mathrm{Sm}$ with alpha energy(22.3 MeV) is (334.700 barn), the cross sections as a function of alpha energy are increased between the range (13.5 to 22.3 MeV) as shown in table (3-6) and in fig.(3-3), and decreased to (0.498 barn) at the alpha energy (13.5 MeV),can we see when alpha energy is increased to continuous that cross section is ranges from low to high.

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum cross sections for the inverse reactions was (51.580 barn) at neutron energy (1.8 MeV) ,and minimum inverse cross-section was (0.043 barn) at (0.8 MeV) as shown in the table (3-12), and in fig.(3-21). Conclude when increased neutron energy the inverse cross sections also increased, it then decreases and increases continuously as the neutron energy remains constant.

In fig.(3-9), in the table(3- 6),when the alpha energy is increased, the stopping power is decreased, were the maximum value of the stopping power in (0.174 MeV/(mg/cm^2)) at the alpha energy about (13.5 MeV)and less value (0.118 MeV/(mg/cm^2)) at energy (24.9 MeV).

In fig. (3-15) two peaks are shown to indicate the maximum value of neutron outcome of the target and respectively (384.331 n /10^6 alpha particle) and (543.741 n /10^6 alpha particle) of the alpha energies about (20.9 MeV) and energy (24.9 MeV) as shown in the table (3-6), can we see when the alpha energy increased also the neutron yield is increased.

Conclude that the high probability to produce $^{147}_{64}\mathrm{Gd}$ is bombarded by $^{144}_{62}\mathrm{Sm}$ with the fast neutron.

(4-2-4) The $^{159}_{65}\mathrm{Tb}(\alpha,\mathrm{n})^{162}_{67}\mathrm{Ho}$ reaction:

In this reaction which has (odd-even) nuclear target $^{159}_{65}\mathrm{Tb}_{94}$,the high probability to produce $^{162}_{67}\mathrm{Ho}$ is bombarded by $^{159}_{65}\mathrm{Tb}$ with alpha energy (15.8 MeV) is (16.794 barn) as shown in the table (3-7), and fig.(3-4). The cross section as a function of alpha energy is decreased at increased of energy with range (15.8 to 46.0)MeV, and the minimum values of cross sections is (3.970 barn) at energy about (46.0 MeV) .

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum cross sections for the inverse reactions was (105.261 barn) at neutron energy (6.1 MeV) ,and minimum inverse cross-section was(24.716 barn) at (36.1 MeV) as shown in the table (3-13),and in fig.(3-22), can be observed that inverse cross-section are decreased when the energy is increased ,also see you when alpha energy is increased that inverse cross-section was decreased.

In fig.(3-10), in the table (3-7) when the alpha energy is increased, the stopping power is decreased, and the maximum value of the stopping power in (0.145 MeV/(mg/cm^2)) at the alpha energy about (15.8 MeV),and the minimum value at (0.072 MeV/(mg/cm^2)) in energy about (46.0 MeV).

In fig.(3-16) the maximum neutron yield is (31.877 n /10^6 alpha particle) at the alpha energy is (27.0 MeV) in the table (3-7), and the neutron yield is decreased to(10.894 n /10^6 alpha particle) when the energy alpha is increased about (46.0 MeV).

Conclude that the high probability to produce $^{162}_{67}\mathrm{Ho}$ is bombarded by $^{159}_{65}\mathrm{Tb}$ with the fast neutron.

(4-2-5) The $^{165}_{67}\mathrm{Ho}\ (\alpha, n)\,^{168}_{69}\mathrm{Tm}$ reaction :

For this reaction which have (odd- even) nuclear target $^{165}_{67}\mathrm{Ho}_{98}$, the high probability to produce $^{168}_{69}\mathrm{Tm}$ is bombarded by $^{165}_{67}\mathrm{Ho}$ with alpha energy (19.5 MeV) is (191.045 barn) as shown in table (3-8) and fig.(3-5), when alpha energies reach (37.7 MeV), they are less valuable to the cross section to (0.208 barn) , this indicates when the increased alpha energies the less of the cross section.

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum value of the cross sections was 1.509 barn) at neutron energy (9.5 MeV) ,and minimum inverse cross-section was (0.001 barn) at (27.9 MeV) as shown in the table (3-14),and in fig.(3-23), can be observed that inverse cross-section are decreased when the energy is increased .

In fig.(3-11) in the table (3-8) the alpha energy is increased, the stopping power is decreased, were the maximum value of the stopping power in (0.049 MeV/(mg/cm^2)) at the alpha energy about (19.5 MeV),and the minimum value at (0.030 MeV/(mg/cm^2)) in energy about (37.7 MeV), can be observed that , the stopping power is decreased, when the energy is increased.

In fig.(3-17) the maximum neutron yield is(768.572n /10$^6\alpha$ - particle) in alpha energy (19.5 MeV), as shown in the table (3-8), and the neutron yield is reduced to the lowest value (1.351 n /10^6 alpha particle) when the energy alpha is increased about (37.7 MeV).

Conclude that the high probability to produce $^{162}_{67}\mathrm{Ho}$ is bombarded by $^{168}_{69}\mathrm{Tm}$ with the fast neutron

(4-2-6) The $^{169}_{69}\mathrm{Tm}(\alpha,n)^{172}_{71}\mathrm{Lu}$ reaction :

For this reaction which have (odd- even) nuclear target $^{169}_{69}\mathrm{Tm}_{90}$,the high probability to produce $^{172}_{71}\mathrm{Lu}$ is bombarded by $^{169}_{69}\mathrm{Tm}$ with alpha energy (20.2 MeV) is (60.179 barn) as shown in table (3-9) and fig.(3-6).

The cross section as a function of alpha energy is decreased of energy with range (15.8 to 46) MeV, and has been the minimum value is (2.321 barn) at energy about (65.4 MeV).

The cross sections of inverse reactions were calculated by applying the reciprocity theory, the maximum value of the cross sections was 155.704 barn) at neutron energy (9.5 MeV) ,and minimum inverse cross-section was (5.898 barn) at (54.1MeV) as shown in the table (3-15),and in fig.(3-24), can be observed that inverse cross-section are decreased when the energy is increased .

In fig.(3-12) in the table (3-9) the alpha energy is increased, the stopping power is decreased, were the maximum value of the stopping power in (0.120 MeV/(mg/cm^2)) at the alpha energy about (20.2 MeV),and the minimum value at (0.055 MeV/(mg/cm^2)) in energy about (65.4 MeV), can be observed that , the stopping power is decreased, when the energy is increased.

In fig.(3-18) the maximum neutron yield in (20.2MeV) for alpha energy is (100.053 n /10^6 alpha particle) as shown in the table (3-9), and the neutron yield is reduced to the lowest value (8.391 n /10^6 alpha particle) when the energy alpha is increased about (65.4 MeV).

Conclude that the high probability to produce $^{169}_{69}\mathrm{Tm}$ is bombarded by $^{172}_{71}\mathrm{Lu}$ with the fast neutron.

(4 -3) Conclusions and suggestions for future works :

(4-3-1) Conclusions :

From it his study the following points were concluded:

1- Separation energy of neutron for $^{144}_{62}$Sm $(\alpha,n)^{147}_{64}$Gd is maximum than other reactions has (8.982 MeV), and separation energy of neutron $^{139}_{57}$La $(\alpha,n)^{142}_{59}$Pr is minimum than other reactions has (7.3513 MeV). Inverse reaction separation energy of alpha particle for $^{162}_{67}$Ho$(n,\alpha)^{159}_{65}$Tb is maximum than other reactions has$(-0.7302$ MeV) to $(-3.2714$ MeV) for $^{147}_{64}$Gd $(n,\alpha)^{144}_{62}$Sm is minimum .

2 - The cross sections of $^{144}_{62}$Sm$(\alpha,n)^{147}_{64}$Gd reaction which has (even - even) and nuclei with magic number of neutron was the highest than other reactions (334.7 barn) at alpha particle energy (22.3MeV), but cross sections of $^{165}_{67}$Ho$(\alpha,n)^{168}_{69}$Tm reaction (odd-even) target nuclei was the less cross sections than for others reactions about (0.208 barn), with alpha particle energy (37.3 MeV) .

3- Neutron yield in $^{165}_{67}$Ho $(\alpha,n)^{168}_{69}$Tm nuclear reaction is greater than other reactions(768.5729 n/10^6 alpha particle) at alpha particle energy (19.5MeV),but the less neutron yield (0.473 n/10^6alpha particle) of $^{139}_{57}$La $(\alpha,n)^{142}_{59}$Pr at alpha particle energy (10.3 MeV).

The result of neutron yield with energy in most nuclear reaction in this work is smooth and it is constant for range.

4- The inverse cross sections of $^{172}_{71}$Lu$(n,\alpha)^{169}_{69}$ Tm was the highest than other reactions (155.704 barn) at neutron energy (9.5 MeV), but less cross sections of $^{168}_{69}$Tm (n,α) $^{165}_{67}$Ho is (0.001 barn) at neutron energy (27.9 MeV).

5- The production of some isotopes is depending on bombarded energy for alpha particle and the atomic number of target ,where these isotopes are very important in many applications such as in Laser fiber optical.

(4-3-2) Suggestions and future work:

1- Study the nuclear properties of (α,n) and (n,α) reactions for excited state.

2- Study the nuclear properties of (α,n) and (n,α) reactions for nucleuses that have even atomic number and compare them with these in present work.

3- Study the nuclear properties of (α,p) and (p,α) by using inverse reactions technique .

4- Use the computer codes that available in the Nuclear Data Centers (high cost codes) to study the most important properties like cross sections theoretically and compare them with the previous available. experimental values, then estimate the neutron yields for (n,n\`) , (p,n) and (γ,n) reactions for the other reactions.

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الخلاصة

تركزت الدراسة الحالية حول دراسة الخواص النووية لبعض نوى عناصر الاتربة النادره من خلال حساب (طاقة التفاعل ، طاقة العتبة ، فائض الكتلة ، وطاقة الربط ، حاجز كولوم و نسبة الحزم) .

تمتلك عناصرالاتربة النادرة مستويات طاقه متعددة تستعمل في تضخيم الاشارات الضوئية في الألياف البصرية لإنتاج الليزر وبشكل افضل من التقنيات القديمة المعروفة وذلك لتشابها في خواصها الكيميائية لامتلاكها التركيب الالكترون ($4f^{0}\,5d^{1}6s^{2}$ - $4f^{14}\,5d^{1}6s^{2}$) والتي ميزتها عن غيرها من العناصر.

تمت دراسة التفاعلات النووية (الفا ، نيوترون) لبعض نوى ذرات العناصر ذات الاعداد الفردية مثل ($^{172}_{71}Lu$, $^{169}_{69}Tm$, $^{159}_{67}Ho$, $^{159}_{65}Tb$, $^{141}_{59}Pr$, $^{139}_{57}La$).

للتفاعلات النووية (الفا ،نيوترون) والتي تتراوح طاقات الفا بين (9.085 – 10.245) ميكا الكترون فولت للتفاعلات التالية :

$$^{139}_{57}La(\alpha,n)\,^{142}_{59}Pr\ ,\ ^{141}_{59}Pr(\alpha,n)\,^{144}_{61}Pm\ .\ ^{159}_{65}Tb(\alpha,n)\,^{162}_{67}Ho,$$

$$^{165}_{67}Ho(\alpha,n)\,^{168}_{69}Tm\ ,\ ^{169}_{69}Tm(\alpha,n)\,^{172}_{71}Lu\ .$$

وكذلك دراسة نوى ذرة العنصر ($^{144}_{62}Sm$) والذي يمثل اعداد زوجية وحسب التفاعل النووي $^{144}_{62}Sm(\alpha,n)\,^{147}_{64}Gd$ وبطاقة الفا حوالي (12.253) ميكا الكترون فولت .

وقد تم حساب المقاطع العرضية للتفاعلات المذكورة في المستوى الارضي وبالاعتماد على برنامج الحاسوب (Matlab.7.6.2008.b) وبخطوات طاقية معينة (0 . 2 ميكا الكترون فولت) ، مختلفة عما هو منشور في المكتبات العالمية :

(EXFOR, ENDF, JENDL, JET, JEFF, BROND, CEND)

وذلك باشـتقـاق المعادلة الشـــبه التـجريبـية والتـي جـدولـت النـتائـج ثم رســـمت ، والتي تربط بين تغير المقطع العرضـي مع مـدى طـاقـات الـفا التي تـم اختـيارها .

وتـم ايضـا حسـاب الحصيلة النيوترونية وفق صيغه زكـلر للتفاعـلات اعـلاه باسـتخدام برنامـج (SRIM-2013) لحسـاب قـدرة الايـقاف والتـي جـدولت النتــائج ايضـا ثم رسـمت، والغرض منه تـحديد طـاقات النـيوترون لإنتاج نظـائر تدخل في انـتاج لـيزر اللـيف البصــري المسـتخدم فـي المجالات الطبـــية والصـناعية والعسـكرية والـزراعية والحاسبات الإلكترونية وفي شتىء المجــالات الاخـرى التـي تخـدم البشـــرية .

كذلـك تـم حســاب المـقاطع العـرضية للـتفاعـلات العكـسية (نـيوترون ، الـفا) لبعض نوى اهداف عـناصـر الاتـربـة النــادرة للمسـتوى الارضـي وباســـتخدام ايضـا المعــادلـة الشــــبه تجــريــــبية للمقـاطــع العكـــسية ، والتي جـدولت النـتائـج ورسـمت التي تـم الحصـول علـيها مـن المــقاطــع العــرضية بطــريقة مـباشــرة وبســـيطة .

$^{142}_{59}\mathrm{Pr}$ $^{139}_{57}\mathrm{La}$ ، $^{146}_{61}\mathrm{Pm}\ (n,\alpha)\ ^{141}_{59}\mathrm{Pr}$ ، $^{147}_{64}\mathrm{Gd}\ (n,\alpha)\ ^{144}_{62}\mathrm{Sm}$

(n,α)

$^{162}_{67}\mathrm{Ho}\ (n,\alpha)\ ^{159}_{65}\mathrm{Tb}$, $^{168}_{69}\mathrm{Tm}(n,\alpha)\,^{165}_{67}\mathrm{Ho}$, $^{172}_{71}\mathrm{La}\ (n,\alpha)\ ^{169}_{69}\mathrm{Tm}$

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بغداد

كلية التربية ابن الهيثم

دراسة الخصائص النووية لبعض عناصر الاتربة النادرة الداخلة في انتاج ليزر الليف البصري

رسالة ماجستير تقدم بها الطالب

سمير هاشم رحيم الدين الخالدي

إلى

قسم الفيزياء / مجلس كلية التربية ابن الهيثم– جامعة بغداد
وهي جزء من متطلبات نيل درجة ماجستير علوم في الفيزياء

بإشراف

ا.م.د. سميرة احمد ابراهيم

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