JIMMA UNIVERSITY
COLLEGE OF NATURAL SCIENCES
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The Role of One Proton Charge Excess in the Cross Section for the Formation and Decay of Compound Nucleus by α emission

A THESIS SUBMITTED TO THE DEPARTMENT OF
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This is to certify that the thesis prepared by Negash Ahmed Graduate Studies entitled "The difference in the compound nucleus reaction cross-section of (n,α) and (p,α) reaction for the same target and energy" in fulfillment of the requirements for the degree of **Master of Science** complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

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Abstract

This research work have been done for the completion of MSc. degree in physics (Nuclear physics) under the title "The Role of One Proton Charge Excess in the Cross Section for the Formation and Decay of Compound Nucleus by α emission". This was to evaluate the effect of a single excess charge on the formation and decay of compound nucleus reaction of the neutron and proton, n and p, induced reactions with the same target and at the same energy. To achieve the objective the selected nuclear reactions were $^{23}Na(n,\alpha)^{20}F$, $^{23}Na(p,\alpha)^{20}Ne$ to represent light mass region, $^{65}Cu(n,\alpha)^{62}Co$,$^{65}Cu(p,\alpha)^{62}Ni$ to represent medium mass region, and $^{90}Zr(n,\alpha)^{87}Sr$ & $^{90}Zr(p,\alpha)^{87}Y$ for the higher mass region.

From the research it was concluded that, the coulomb barrier available when the proton projectile approaches the ^{23}Na target nucleus reduces the chance of of reaction between the projectile and the target. This suppresses the reaction cross section for the compound nucleus in light mass region by proton projectile than neutron projectile at the same energy and target. But for the medium and heavy mass region compound nucleus reaction cross section by proton on the same target and the same projectile energy is higher due to the decay of the compound nucleus by alpha particle emission gets supported by the coulomb energy between the residual nucleus and the outgoing particle.

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Chapter 1

Introduction

1.1 Back Ground

Many efforts have been made during the last decade by nuclear physicists to understand the information that nuclear reaction provide knowledge about nature of nuclear force, nuclear structure, size, shape and other parameters related to the nucleus. Whenever energetic particle fall up on the bulk matter there is a probability[1] that nuclear reaction can take place [1] and Rutherford was the first physicist who perform nuclear reaction. The disintegration of a nitrogen atom by $\alpha-$ particle represented by an equation

$$^{4}_{2}He + ^{14}_{7}N \rightarrow [^{18}_{9}F] \rightarrow ^{17}_{8}O + ^{1}_{1}H \tag{1.1}$$

The symbol in brackets stands for the unstable nucleus formed as a result of absorbtion [2] $\alpha-$ particle of by nitrogen nucleus; this kind is often called a compound nucleus. In nuclear physics, a nuclear reaction is a process in which two nuclear particles or nuclei collide to produce products either different from the initial particles or themselves in excited state or ground state. In principle, a reaction can involve the collision of two nuclei or subatomic particles, but the probability of three or more particles colliding at the same time is extremely small, and such an event is exceptionally rare.

Compound nuclear reaction; Is a type of nuclear reaction, the incoming particle or projectile and target nucleus equally sharing of energy before the out going particle is ejecting . This nuclear reaction leads to the sharp peak of the quasi-stable nuclear state for particular value of resonance energy. Reaction that proceeds through the compound nucleus to be a two step process ;

i) the formation of compound nucleus.

ii) the decay of compound nucleus.

Compound nucleus reaction cross section is the probability of the formation of the compound nucleus in one channel and decay of the compound nucleus in another channel[3]. This depends on different factors, like the entrance and out going channel, projectile, target, time, etc. In this research, the dependence of the compound nucleus cross section on charge,single electron charge have been studied using six different reactions.

1.2 Statement of the Problem

The dependence of compound nucleus reaction cross section on a single electron charge can be studied in different techniques based on the theoretical calculation of cross section using six different reactions. The following questions were answered on this research.

1. What are the calculated value of the compound nucleus reaction cross section for the reaction of
    - ${}^{23}_{11}Na(n,\alpha)^{20}_{9}F$?
    - ${}^{23}_{11}Na(p,\alpha)^{20}_{10}Ne$?
    - ${}^{65}_{29}Cu(n,\alpha)^{62}_{27}Co$?
    - ${}^{65}_{29}Cu(p,\alpha)^{62}_{28}Ni$?
    - ${}^{90}_{40}Zr(n,\alpha)^{87}_{38}Sr$?
    - ${}^{90}_{40}Zr(p,\alpha)^{87}_{39}Y$?
2. How valid are the calculated values of cross section compared to the experimental values ?
3. How do the cross section for the formation and decay of compound nucleus depends on a single electron charge excess?

1.3 Objectives

1.3.1 General Objective

The main objective of this study is to examine the effect of one proton charge excess on the formation and decay of compound nucleus using six different reactions.

1.3.2 Specific Objectives

The specific objectives of the studies were;

1. To calculate the value of the compound nucleus reaction cross-section for the six reactions.
   - ${}^{23}_{11}Na(n,\alpha){}^{20}_{9}F$
   - ${}^{23}_{11}Na(p,\alpha){}^{20}_{10}Ne$
   - ${}^{65}_{29}Cu(n,\alpha){}^{62}_{27}Co$
   - ${}^{65}_{29}Cu(p,\alpha){}^{62}_{28}Ni$
   - ${}^{90}_{40}Zr(n,\alpha){}^{87}_{38}Sr$
   - ${}^{90}_{40}Zr(p,\alpha){}^{87}_{39}Y$
2. To valid the calculated reaction cross-section of the compound nucleus compared to the experimental value for the six reactions.
3. To investigate the cross section for the formation and decay of compound nucleus depending on a single electron charge excess

1.4 Scope of the research

This research is studied in a depth limited to Compiles information from different literatures about the effect of single charge excess betweenon n and p induced reactions, Calculate, using a computer code is called complet, the cross section of compound nucleus for six different reactions with single charge excess. Validate the result of the cross- section per each isobar and check the effect of single charge excess on the reaction and draw conclusion.

1.5 Significance

- It helps the researcher to gain more knowledge in the course of the work.
- The advantage of this research are helps to give some information on the effect of single charge excess for the cross section of the compound nucleus.
- It can be used as a reference for further studies.

1.6 Limitation of the study

The main lacks that faced during this research are lack of senior nuclear laboratory, lack of fast internet access, lack of reference materials in a related area in the library and insufficient time given for the work. This limitations might cause error in the research out put.

Chapter 2

Literature Review

2.1 Nuclear reactions

The study of nuclear reactions is important for a number of reasons. Progress in the understanding of nuclear reactions has occurred at a faster pace and generally a higher level of sophistication has been achieved compared to similar studies of chemical reactions.

The approaches used to understand nuclear reactions are of value to any chemist who wishes a deeper insight into chemical reactions. There are certain nuclear reactions that play a prominent role in the affairs of man and our understanding of the natural world in which we live . For example, life on earth would not be possible without the energy provided to us by the sun. That energy is the energy released in the nuclear reactions that drive the sun and other stars. For better or worse, the nuclear reactions, fission and fusion, are the basis for nuclear weapons, which have shaped much of the geopolitical dialog for the last 50 years. Apart from the intrinsically interesting nature of these dynamic processes, their practical importance would be enough to justify their study.

Nuclear reactions and nuclear scattering are used to measure the properties of nuclei[4]. Reactions that exchange energy or nucleons can be used to measure the energies of binding and excitation. A particle accelerator produces a beam of high-velocity charged particles (electrons, protons, α, or "heavy ion"), which then strikes a target nucleus. Nuclear reactions can also be produced in nature by high-velocity particles from cosmic rays, for instance in the upper atmosphere or in space. Beams of neutrons can be obtained from nuclear reactors or as secondary products when a charged-particle beam knocks out weakly-bound neutrons from a target nucleus. Nuclear reactions can also be produced by beams of photons, and neutrinos.

In order for a nuclear reaction to occur, the nucleons in the incident particle, or projectile, must interact with the nucleons in the target. Thus the energy must be high enough to overcome the natural electromagnetic repulsion between the protons. This energy "barrier" is called the Coulomb barrier. If the energy is below the barrier, the nuclei will bounce off each other. Early experiments by Rutherford used low-energy alpha particles from naturally radioactive material to bounce off target atoms and measure the size of the target nuclei. When a collision occurs between the incident particle and a target nucleus, either the beam particle scatters elastically leaving the target nucleus in its ground state or the target nucleus is internally excited and subsequently decays by emitting radiation or nucleons.

In order to write an equation for a nuclear reaction, we must first establish some basic rules. If a target nucleus X is bombarded by a particle 'a' and results in a nucleus Y with emitted particle 'b',this is commonly written in one of two ways as.[4]

$$a + X \rightarrow Y + b, or \quad X(a, b)Y \tag{2.1}$$

where,

a -is a projectile (bombarding particle)(incident particle)

b -is an emitted particle (outgoing particle)

X-is target nucleus and

Y-is the residual nucleus (recoil nucleus)[5].

2.1.1 Classification of nuclear reactions

The reaction of an incident particle with an atomic nucleus can take place in many ways. In studies of light-ion induced nuclear reactions one distinguishes between three different mechanisms: direct, compound and per-equilibrium nuclear reactions. These reaction processes can be subdivided according to time scales or, equivalently, the number of intra nuclear collisions taking place before emission[6]. Furthermore each mechanism preferentially excites certain parts of the nuclear level spectrum and is characterized by different types of angular distributions.

Compound nuclear reaction

In 1936, Bohr proposed his theory of the compound nucleus, which has been extremely useful in the correlation and interpretation of nuclear reactions.

Compound processes involve long reaction times ($\sim 10^{-18}$ seconds)[7] and are predominant at low energies (below 10 MeV).The compound reaction mechanism is known to proceed by many intra nuclear collision. The incident particle is captured by the target nucleus to form a compound nucleus.Subsequently, the incident energy is shared among the other nucleons and after a long time a sufficient amount of energy may be accumulated for one nucleon (or group of nucleons) to escape. Apart from conservation of total energy and total angular momentum, the outgoing and incident channel are completely uncorrelated.

Bohr assumed that a nuclear reaction takes place in two steps:
Firstly, The incident particle is absorbed by the initial,or target,nucleus to form a compound nucleus disintegrates by ejecting a particle(proton, neu-

tron, α-particle) or γ-rays, leaving the final, or product, nucleus. secondly, the mode of disintegration of the compound nucleus is independent of the way in which it is formed, and depends only on properties of the compound nucleus itself,such as its energy and angular momentum.The two steps of the reaction can then be considered as separate processes.

1.Incident particle + target nucleus → compound nucleus

2.Compound nucleus → product nucleus + outgoing particle.

2.1.2 Reaction cross section(δ)

Nuclear reaction cross section is the measurement of probability of the reaction. This is defined in terms of number of events produced (number of particles emitted after reaction) for specific number of incident particle or it can also defined in terms of number of nuclei transformed per specific number of incident particles[8]. The Nuclear reaction cross section is the effective area of the nuclei shown to the incident beam or it is the effective area of the nuclei as seen by the incident beam. Roughly speaking, the cross section is a measure of the relative probability for the reaction to occur[9]. This is represented by:

$$\delta = \frac{I}{n} \tag{2.2}$$

Where I = Number of particular types of events per unit time per nuclei.
n = Number of incident particles per unit time per unit area. The geometric cross-section that a nucleus presents to a beam of particles is πr^2. If we use 6×10^{-15} m as an average value for the nuclear radius, the value of πr^2 becomes $3.14(6 \times 10^{-15})^2 \approx 10^{-28} m^2$. This geometric cross-section of nuclei is reflected in the unit of reaction probability which is the barn, where $1b$

$=10^{-28} m^2$. The cross section is directly related to the difference between the final and initial nuclear states[2] and does not involve the states of all the other nucleons. The study of the cross sections of the nuclear reaction is important for two reasons:

i. For empirical knowledge for various applied purposes, e.g. in fission or fusion studies required for designing reactors or for various fission devices.

ii. For understanding the reaction mechanism.

Classical estimation of reaction cross section for the formation of compound nucleus

The cross section for a compound nuclear reaction can be written as the product of two factors, the probability of forming the compound nucleus and the probability that the compound nucleus decays[10].Consider the reaction of an uncharged particle (a neutron) as shown in the Fig 1:

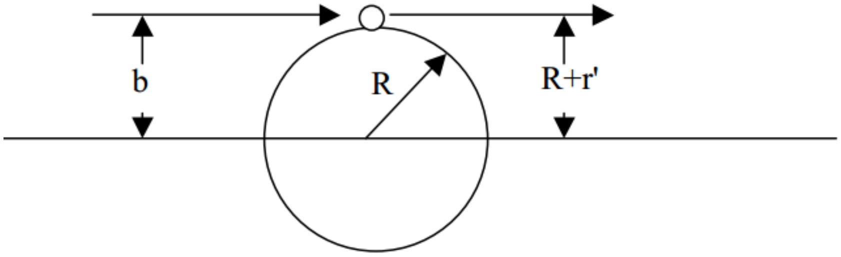

Figure 2.1: Schematic diagram of a grazing collision of a neutron with a nucleus

The neutron makes a grazing collision with the nucleus. The impact parameter b is taken to be the sum of the radii of the projectile and target nuclei[11]. Thus the cross section can be written as

$$\delta \approx \pi(R + r')^2 = \pi r_o^2 (A_P^{\frac{1}{3}} + A_T^{\frac{1}{3}})^2 \tag{2.3}$$

Where r' is the radius of the projectile. Applying classical mechanics to this problem, we can write for orbital angular momentum l,

$$l = \overrightarrow{r} \times \overrightarrow{p} = pb \tag{2.4}$$

the momentum,p is given by

$$P = \frac{\hbar}{\lambda\!\!\!^{-}} \tag{2.5}$$

Thus we have

$$l = \frac{\hbar b}{\lambda\!\!\!^{-}}, b = \frac{l \lambda\!\!\!^{-}}{\hbar} \tag{2.6}$$

where $\hbar$ and $\lambda\!\!\!^{-}$ are the reduced Planck's constant and reduced de-Broglie wave length. This is not quite right because l is quantized but b is not. We get around this by associating b with certain rings or zones on the target. As shown in Fig:2 suggests that for head-on collisions(l=0) , the range of b is from 0 to λ while for $l = 1$ collisions, the range of b is from λ to 2λ. Thus the cross section is larger for larger impact parameters and these larger impact parameters are associated with larger angular momenta[12]. We can write the cross section for a specific value of as

$$\delta_l = \pi(l + 1)^2 \lambda\!\!\!^{-2} - \pi l^2 \lambda\!\!\!^{-2} \tag{2.7}$$

$$\delta_l = \pi \lambda\!\!\!^{-2}(l^2 + 2l + 1 - l^2) = \pi \lambda\!\!\!^{-2}(2l + 1) \tag{2.8}$$

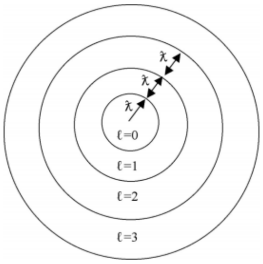

Figure 2.2: Schematic bulls-eye view of the target nucleus

The total reaction cross section is obtained by summing over all l values as

$$\delta_{total} = \sum_{i}(\delta_i) = \sum_{l=0}^{l_{max}} \pi ƛ^2(2l+1) = \pi^2 ƛ^2 \sum_{l=0}^{l_{max}}(2l+1) = \pi ƛ^2(l_{max}+1)^2 \quad (2.9)$$

We can write for the maximum angular momentum, l_{max},

$$l_{max} = \frac{R}{ƛ} \quad (2.10)$$

Thus we have for the total cross section

$$\delta_{total} = \pi(R + ƛ)^2 \quad (2.11)$$

The total cross section is proportional to the size of the target nucleus and the"*size*" of the projectile nucleus. Wave length of the projectile, λ goes to infinity as the projectile energy goes to zero, the cross sections for neutrons at low energies can be very large.

In the case of charged particle the incident beam is deviated by a potential

$$V(_R) = \frac{Z_p Z_t e^2}{R} \tag{2.12}$$

Where $V(_R)$, Z_p, Z_t, e and R are Coulomb barrier, number of proton of projectile, number of proton of target, proton charge and radius of the target respectively. The particle reaching the nuclear surface are those with impact parameter less than radius(R) of the nucleus. Thus the cross-section for the formation of the compound nucleus by charged projectile is given by

$$\sigma_{total} = \begin{cases} \pi R^2 (1 - \frac{V_R}{\epsilon_p}) & for \epsilon_p > V_R \\ 0 & for \epsilon_p \leq V_R \end{cases} \tag{2.13}$$

Where ϵ_p is kinetic energy of the projectile.

Quantum mechanical consideration of cross section

The above discussion is based upon classical mechanics. We need to indicate how the problem would look if we used quantum mechanics to treat it. In quantum mechanics, we can write a similar expression for the total reaction cross section.

$$\delta_{total} = \pi \lambda\!\!\!^{-}{}^2 \sum_{l=0}^{\infty} (2l + 1) T_l \tag{2.14}$$

where the transmission coefficientT_l varies between 0 and 1 .

2.1.3 Conservation laws

In analyzing nuclear reactions several conservation laws will be applied. Some of these include:

i . **Conservation of total energy and linear momentum**: - which can be used to relate the unknown but perhaps measurable energies of the products to the known and controllable energy of the projectile.We can thus use the measured energy of projectile to deduce the excitation energy of states of the product or the mass difference between the target and the product[13].

ii . **Conservation of proton and neutron number** (conservation of charge and mass number):- is a result of the low energy of the process, in which no meson formation or quark rearrangement take place. At higher energies we still conserve total nucleon number, but at low energy we conserve separately proton number and neutron number.

iii .Conservation of parity:- also applies the net parity before the reaction must equal the net parity after the reaction[14]. If we know the orbital angular momentum of the outgoing particle, we can use the $(-1)^l$ rule and the other known parities in the reaction to deduce unknown parities of excited states.

iv . Conservation of spin:- spin or angular momentum is a quantity which measures how quickly an object is rotating or revolving about a fixed line called an axis. It enables us to relate the spin alignments of the reacting particles and the orbital angular momentum carried by the outgoing particle, which can be deduced by measuring its angular distribution. Classically, it is given by the product mrv of the mass of the object, its distance from the axis, and its velocity perpendicular to the line between it and the axis. The conservation of angular momentum is related to the fact that the laws of physics don't depend on the orientation of particular coordinate system.

2.1.4 Energetics of nuclear reactions

Conservation of total relativistic energy in our basic reaction gives

$$m_x c^2 + T_x + m_a c^2 + T_a = m_y c^2 + T_y + m_b c^2 + T_b \tag{2.15}$$

Where the Ts are kinetic energies (for which we can use the non-relativistic approximation $\frac{1}{2}mv^2$ at low energy) and the $m's$ are rest masses. We define the reaction Q value, in analogy with radioactive decay Q values, as the initial mass energy minus the final mass energy:[15]

$$Q = (m_{initial} - m_{final})c^2 = (m_x + m_a - m_y - m_b)c^2 \tag{2.16}$$

which is the same as the excess kinetic energy of the final products:

$$Q = T_{final} - T_{initial} = T_y + T_b - T_x - T_a \tag{2.17}$$

The Q value may be positive, negative, or zero. If $Q > 0$ $(m_{initial} > m_{final})$ or$(T_{final} > T_{initial})$ the reaction is said to be exoergic or exothermic: in this case nuclear mass or binding energy is released as kinetic energy of the final products, When $Q < 0$ $m_{initial} < m_{final}$ or $T_{final} < T_{initial})$ the reaction is endoergic or endothermic, and initial kinetic energy is converted into nuclear mass or binding energy. The changes in mass and energy must of course be related by the familiar expression from special relativity. $E = mc^2$ any change in the kinetic energy of the system of reacting particles must be balanced by an equal change in its rest energy.

Chapter 3

Material and Methods

3.1 Materials needed

During this research the following material has been used.

- Computer, flash disc.
- Stationary materials.
- Printer and accessories.
- References like journals, books, websites, thesis and dissertation.
- COMPLET, Microsoft Office EXCEL 2007.

3.2 Methodology

3.2.1 Data from Literature

Different references has been explored to assess information on the cross-section of the reactions

- $^{23}_{11}Na(n,\alpha)^{20}_{9}F$
- $^{23}_{11}Na(p,\alpha)^{20}_{10}Ne.$
- $^{65}_{29}Cu(n,\alpha)^{62}_{27}Co$
- $^{65}_{29}Cu(p,\alpha)^{62}_{28}Ni.$
- $^{90}_{40}Zr(n,\alpha)^{87}_{38}Sr$
- $^{90}_{40}Zr(p,\alpha)^{87}_{39}Y.$

These reactions are chosen because they set with targets in low, medium and high mass regions. This helps to check the behavior of the cross section in different mass regions.

Using an experimental Compound nucleus cross section for all the six reactions have been downloaded from EXFOR.dat center.

3.2.2 Computational Method

After having gathered experimental data,calculation excitation function have been made using a FORTRAN 77 based computational nuclear reaction code for exactly the same energy projectile particles per each three targets

^{23}Na,^{65}Cu &^{90}Zr, as in experiment. The projectiles are proton and neutron the same nuclear particle which differs by one electron charge. This helped to compare the calculated excitation function with the experimental data for all the reactions considered during the research .The calculated excitation functions data has been presented in tables together with experimental data. Both the experimental and calculated values were plotted in graphs as function of projectile energy .

Discussion on the validity of the calculated excitation function in compression with experimental data has been done. After the validity discussion compression of cross section of compound nucleus with the regard to the same reactions except their difference in the charge of the projectiles and compound nucleus formed during each reaction by one proton charge has been done. From the discussion,conclusion on the effect of a single charge excess for the cross section of a compound nucleus has been inferred. A computational nuclear reaction code called COMPLET has been used during the calculation of cross-sections for all reactions. The detail of using the code is given in appendix.

Chapter 4

Result and Discussion

Here the cross section for compound nucleus reaction were calculated using a computational code, [16] for the reactions: $^{23}Na(n,\alpha)^{20}F$, $^{23}Na(p,\alpha)^{20}Ne$, $^{65}Cu(n,\alpha)^{62}Co$, $^{65}Cu(p,\alpha)^{62}Ni$, $^{90}Zr(n,\alpha)^{87}Sr$ and $^{90}Zr(p,\alpha)^{87}Y$ taking the same energy of projectile. The results were as presented in the following sections.

4.1 Reaction of $^{23}Na(n,\alpha)^{20}F$

4.1.1 Experimental Reaction Cross- section(σ_{exp}) of $^{23}Na(n,\alpha)^{20}F$

The reaction cross section of $^{23}Na(n,\alpha)^{20}F$ experimentally have been done by authors C.F.Williamson in 1961 using the projectile(neutron) energy for 16.8 Mev and 18.2 Mev . The result obtained were downloaded from EXFOR data center and presented in Table 4.1

Table 4.1: Experimental reaction cross- section of $^{23}Na(n,\alpha)^{20}F$

E(Mev)	$\delta_{exp}(mb)$
16.8	69
18.2	54

4.1.2 Calculated Compound Nucleus Reaction Cross-Section ($\delta_{theo.}$) of $^{23}Na(n,\alpha)^{20}F$

The calculation of the compound nucleus reaction cross -section for the reaction $^{23}Na(n,\alpha)^{29}F$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code a neutron projectile of energy 16.8 Mev and 18.2 Mev have been selected, the same energy as the experiment. The result of (the output from the code) the calculation was as shown in the Table4.2 below.

Table 4.2: calculated reaction cross section of $^{23}Na(n,\alpha)^{20}F$

E(Mev)	$\sigma_{theo}(mb)$
16.8	49.79
18.2	33.89

Discussion on the Validity of Calculated Data of $^{23}Na(n,\alpha)^{20}F$

As can be seen in section 4.1.1; Table 4.1 and in section 4.1.2 ; Table 4.2, the experimental reaction cross- section and the calculated reaction cross-section for the compound nucleus reaction in the given energies are under estimated. For the energy 16.8 Mev, the calculated cross-section is less than the experimental by 19.2 mb and it is less by 20.11 mb for the 18.2 Mev projectile energy. The calculated result under estimated compared to experimental value, and the result is plotted in the Fig. 4.1 This shows the COMPLET code calculation gives a valid result for the reaction in the given energy range for the compound nucleus cross-section.

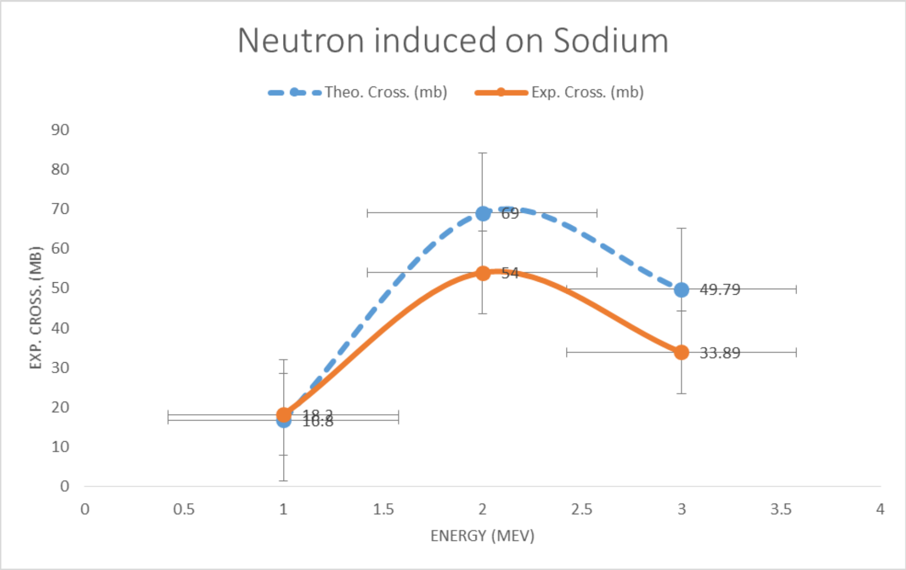

Figure 4.1: Experimental reaction cross section and theoretical compound reaction cross section for the reaction of $^{23}Na(n,\alpha)^{20}F$

In this Figure 4.1 the value of experimental reaction cross -section presented by red(solid line) color and the theoretical value of compound reaction cross section is symbolized by blue(broken line) color.The theoretically calculated data using the COMPLET code is almost approximate to the experimental data.

4.2 Reaction of $^{23}Na(p,\alpha)^{20}Ne$

4.2.1 Experimental Reaction Cross- section of Reaction $^{23}Na(p,\alpha)^{20}Ne$

The reaction cross-section of $^{23}Na(p,\alpha)^{20}Ne$ experimentally have been done by authors W.Buck, F.Hoyler, A.Stabler, G.Staudt, H.V.Klapdor, H.Oeschler in 1983 using the projectile(proton) energy for 16.8 Mev and 18.2 Mev [17]. The result obtained were down loaded from ExFOR data center and presented in Table 4.3 below.

Table 4.3: Experimental reaction cross section of $^{23}Na(p,\alpha)^{20}Ne$

E(Mev)	$\sigma_{exp.}(mb)$
16.8	0.147446
18.2	0.866

4.2.2 Calculated Compound Nucleus Reaction Cross-section($\sigma_{theo.}$) of $^{23}Na(p,\alpha)^{20}Ne$

The calculation of the compound nucleus reaction cross- section for the reaction $^{23}Na(p,\alpha)^{20}Ne$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code a proton projectile of energy 16.8 Mev and 18.2 Mev have been selected, the same energy as the experiment as well as the same energy selected in section 4.1.2 for neutron projectile .

The result of (the output from the code) the calculation was as shown in the Table 4.4 below.

Table 4.4: Calculated compound reaction cross-section of $^{23}Na(p,\alpha)^{20}Ne$

E(Mev)	$\sigma_{theo.}(mb)$
16.8	0.0736
18.2	0.432

4.2.3 Discussion on the Validity of Calculated Data of $^{23}Na(p,\alpha)^{20}Ne$

It can be seen that the reaction cross section displayed in Table4.3 section of 4.2.1 and in table 4.4 section of 4.2.2 there is a good agreement between the experimental reaction cross section and calculated compound reaction cross section.For the energy 16.8 Mev, the calculated reaction cross-section less than the experimental by 0.0738 mb and it is less by 0.434 mb for the 18.2 Mev projectile energy.The calculated result it gave approximately similar result near the experimental value and the result is plotted in the graph Fig4.2.3. This shows, the COMPLET code calculation gives a valid result for the reaction in the given energy values.

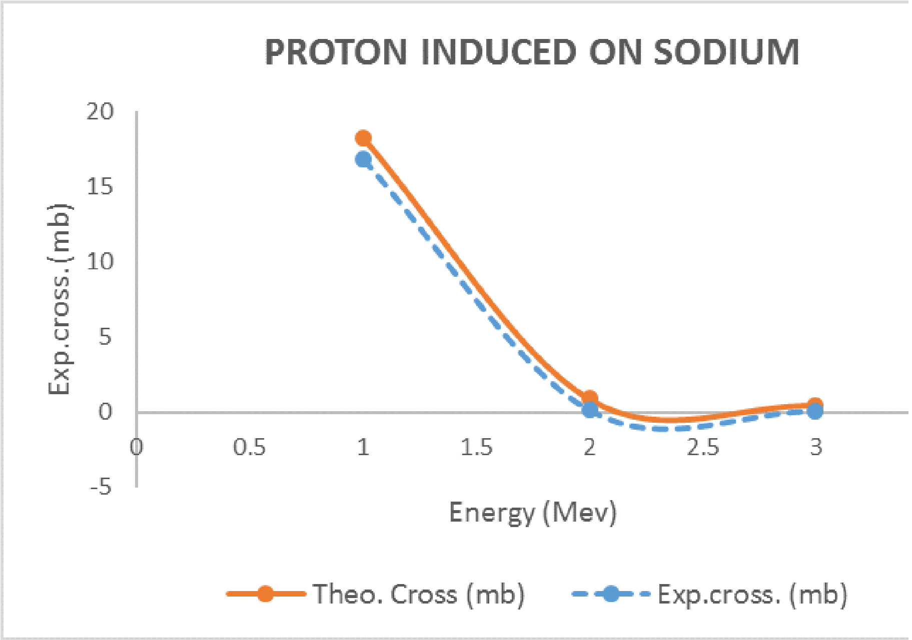

Figure 4.2: Experimental reaction cross section and calculated compound reaction cross section for the reaction of $^{23}Na(p,\alpha)^{20}Ne$

4.3 The Reaction of $^{65}Cu(n,\alpha)^{62}Co$

4.3.1 The Experimental Reaction Cross- section of $^{65}Cu(n,\alpha)^{62}Co$

In 1994 the reaction cross-section of $^{65}Cu(n,\alpha)^{62}Co$ have been done by authors by F.Cserpak, S.Sudar, J.Csikai and S.M.Qaim.They used 6.3 Mev, 9.18 Mev, 10.1 Mev and 11 Mev for projectile(neutron) energy. The result obtained were down loaded from EXFOR data center and presented in Table 4.5 below.

Table 4.5: The experimental reaction cross section of$^{65}Cu(n,\alpha)^{62}Co$

E(Mev)	$\sigma_{exp.}(mb)$
6.3	0.02
9.18	0.86
10.1	1.26
11	1.85

4.3.2 Calculated Compound Nucleus Reaction Cross - section($\sigma_{theo.}$) of $^{65}Cu(n,\alpha)^{62}Co$

The calculation of the compound nucleus reaction cross- section for the reaction $^{65}Cu(n,\alpha)^{62}Co$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code a neutron projectile of energy 6.3 Mev, 9.18 Mev,10.1 Mev and 11 Mev have been selected, the same energy as the experiment. The result of (the output from the code) the calculation was as shown in the Table 4.6 below.

Table 4.6: Calculated compound nucleus reaction cross section of $^{65}Cu(n,\alpha)^{62}Co$

E(Mev)	$\sigma_{theo.}(mb)$
6.3	0.0073
9.18	0.67
10.1	0.87
11	1.06

Discussion on the Validity of Calculated Data of $^{65}Cu(n,\alpha)^{62}Co$

For the discussion the validity of calculated compound nucleus reaction cross-section of $^{65}Cu(n,\alpha)^{62}Co$ with its experimental reaction cross-section discussed in section 4.3.1 . Focused on Table 4.7 below that arranged from Table 4.5 of section 4.3.1 and Table 4.6 of section 4.3.2.

Table 4.7: Difference of reaction cross-section between Calculated compound nucleus reaction cross- section and experimental reaction cross- section of $^{65}Cu(n,\alpha)^{62}Co$

E(Mev)	$\sigma_{exp}(mb)$	$\sigma_{theo}(mb)$	$\Delta\sigma = \sigma_{exp}(mb) - \sigma_{theo}(mb)$
6.3	0.02	0.0073	0.0127
9.18	0.86	0.67	0.19
10.1	1.26	0.87	0.391
11	1.85	1.06	0.79

As can be seen Table 4.7;The value of calculated compound nucleus reaction cross- section of $^{65}Cu(n,\alpha)^{62}Co$ from the value of its experimental reaction cross- section for each given energy of the projectile is slightly less in value. The calculated result gave approximately similar result near the experimental value, and the result is plotted in the Fig 4.3. This shows the COMPLET code calculation gives a valid result for the reaction in the given energy.

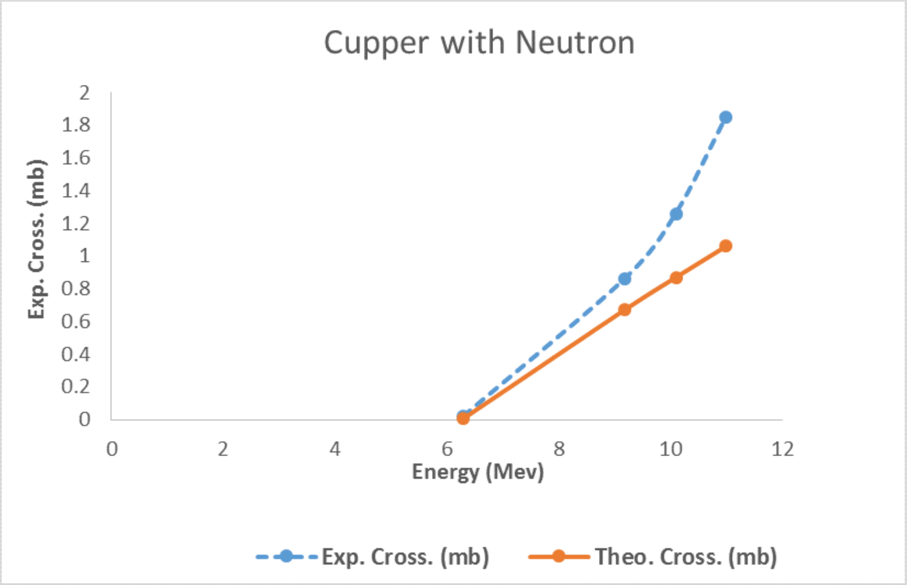

Figure 4.3: Experimental reaction cross section and calculated compound reaction cross section for the reaction of $^{65}Cu(n, \alpha)^{62}Co$

4.4 Reaction of $^{65}Cu(p, \alpha)^{62}Ni$

4.4.1 Experimental Reaction Cross- Section of $^{65}Cu(p, \alpha)^{62}Ni$

The Experimental reaction cross- section of $^{65}Cu(p, \alpha)^{62}Ni$ have been done by authors J.Benveniste, R.Booth, A.Mitchell in 1961.They used 6.3 Mev, 9.18 Mev, 10.1 Mev and 11 Mev energies for proton projectile. The result obtained were down loaded from EXFOR data center and presented in Table 4.8; below.

Table 4.8: The experimental reaction cross section of$^{65}Cu(p,\alpha)^{62}Ni$

E(Mev)	$\sigma_{exp.}(mb)$
6.3	37
9.18	26
10.1	22
11	34

4.4.2 Calculated Compound Nucleus Reaction Cross Section of($\sigma_{theo.}$) of $^{65}Cu(p,\alpha)^{62}Ni$

The calculation of the compound nucleus reaction cross- section for the reaction $^{65}Cu(p,\alpha)^{62}Ni$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code a proton projectile of energy 6.3 Mev, 9.18 Mev, 10.1 Mev and 11 Mev have been selected, the same energy as the experiment and the same energy selected for the reaction in section 4.3.2 above for the neutron projectile. The result of (the output from the code) the calculation was as shown in the Table 4.9 below.

Table 4.9: Calculated compound nucleus reaction cross section of $^{65}Cu(p,\alpha)^{62}Ni$

E(Mev)	$\sigma_{theo.}(mb)$
6.3	29.75
9.18	18.98
10.1	14.39
11	26.63

4.4.3 Discussion on the Validity of Calculated Data of $^{65}Cu(p,\alpha)^{62}Co$

For the discussion the validity of calculated compound nucleus reaction cross-section of $^{65}Cu(p,\alpha)^{62}Ni$ with its experimental reaction cross-section discussed in section 4.4. Focused on Table 4.10 below that arranged from Table 4.8 of section 4.4.1 and Table 4.9 of section 4.4.2.

Table 4.10: The difference of reaction cross- section between experimental and calculated compound nucleus of $^{65}Cu(p,\alpha)^{62}Ni$

E(Mev)	$\sigma_{exp}(mb)$	$\sigma_{theo}(mb)$	$\Delta\sigma = \sigma_{exp} - \sigma_{theo}(mb)$
6.3	37	29.75	7.25
9.18	26	18.98	7.02
10.1	22	14.39	7.61
11	34	26.63	7.37

As can be seen easily from Table4.10 , above the value of the calculated reaction cross-section for the reaction of $^{65}Cu(p,\alpha)^{62}Ni$ to its experimental reaction cross-section is under estimated.

The result is plotted in the Fig4.4 . This shows the COMPLET code calculation gives a valid result for the reaction in the given energy values.

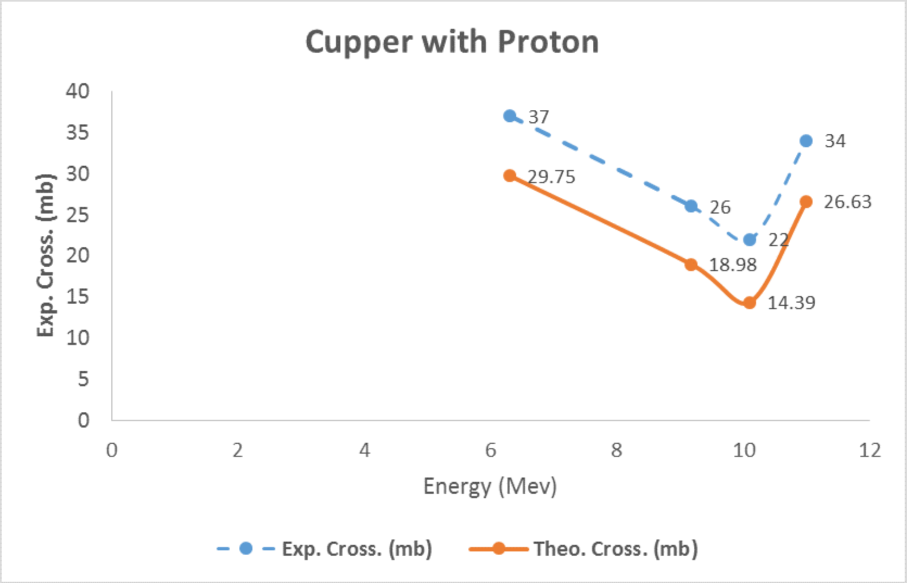

Figure 4.4: Experimental reaction cross- section and calculated compound reaction cross- section for the reaction of ${}^{65}Cu(p,\alpha)^{62}Ni$

4.5 Reaction of ${}^{90}Zr(n,\alpha)^{87}Sr$

4.5.1 Experimental Reaction Cross- section of ${}^{90}Zr(n,\alpha)^{87}Sr$

The Experimental reaction cross-section of ${}^{90}Zr(n,\alpha)^{87}Sr$ have been done by authors V.Semkova, E.Bauge, A.J.M.Plompen, D.L.Smith, A.Moens, R.J.Tornin, V.Avrigeanu, P.Reimer, S.Sudar, A.Koning & R.Forrest in 2010. They used 15.5 Mev, 16.5 Mev, 17.3 Mev , 18.2 Mev and 19.2 Mev energies for neutron projectile.The result obtained were down loaded from EXFOR data center and presented in Table 4.11; below.

Table 4.11: Experimental reaction cross section for the reaction of $^{90}Zr(n,\alpha)^{87}Sr$

E(Mev)	$\sigma_{exp.}(mb)$
15.5	4.3
16.5	4.7
17.3	4.8
18.2	4.8
19.2	4.5

4.5.2 Calculated Compound Nucleus Reaction Cross-section of $(\sigma_{theo.})^{90}Zr(n,\alpha)^{87}Sr$

The calculation of the compound nucleus reaction cross- section for the reaction $^{90}Zr(n,\alpha)^{87}Sr$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code of a neutron projectile of energy 15.5 Mev, 16.5 Mev, 17.3 Mev , 18.2 Mev and 19.2 Mev have been selected, the same energy as the experiment .The result of (the output from the code) the calculation was as shown in the Table 4.12 below.

Table 4.12: Calculated compound nucleus reaction cross section of $^{90}Zr(n,\alpha)^{87}Sr$

E(Mev)	$\sigma_{theo.}(mb)$
15.5	2.67
16.5	2.973
17.3	3.131
18.2	3.092
19.2	2.831

4.5.3 Discussion on the Validity of Calculated data of $^{90}Zr(n,\alpha)^{87}Sr$

The validity of calculated compound nucleus reaction cross - section of $^{65}Cu(p,\alpha)^{62}Ni$ with its experimental reaction cross-section was discussed. By focusing on Table 4.13 below that arranged from Table4.11 of section 4.5.1 and Table 4.12 of section 4.5.2

Table 4.13: The difference of reaction cross section between experimental and calculated compound nucleus of $^{90}Zr(n,\alpha)^{87}Sr$

E(Mev)	$\sigma_{exp}(mb)$	$\sigma_{theo}(mb)$	$\Delta\sigma = \sigma_{exp} - \sigma_{theo}(mb)$
15.5	4.3	2.67	1.63
16.5	4.7	2.973	1.727
17.3	4.8	3.131	1.669
18.2	4.8	3.092	1.708
19.2	4.5	2.831	1.16

the value of the calculated reaction cross-section for the reaction of $^{90}Zr(n,\alpha)^{87}Sr$ to its value of experimental reaction cross-section approximately similar .

The result is plotted in the Fig4.5 . This shows the COMPLET code calculation gives a valid result for the reaction in the given energy values.

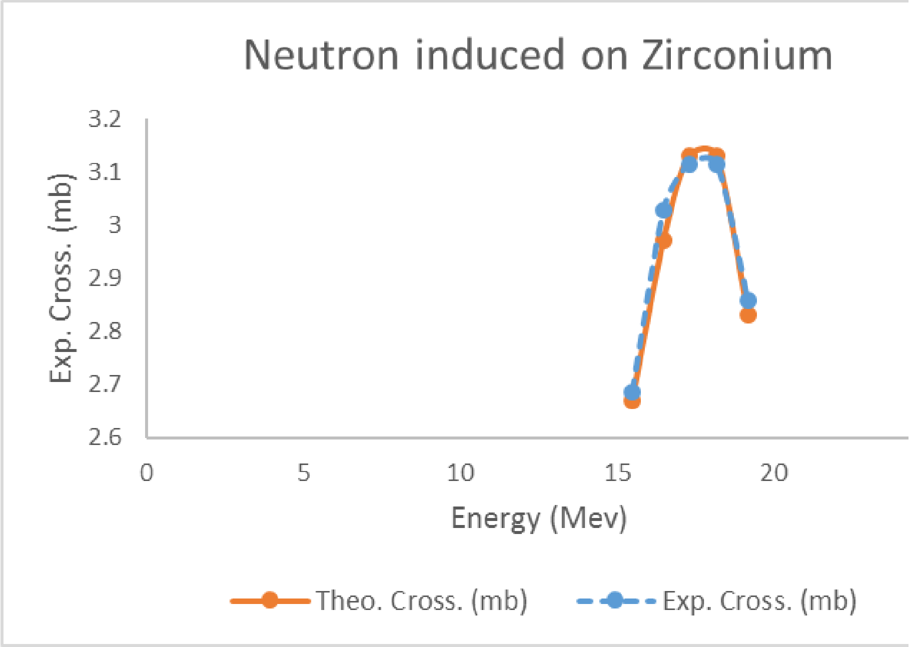

Figure 4.5: Experimental reaction cross section and theoretical compound reaction cross section for the reaction of $^{90}Zr(n,\alpha)^{87}Sr$

4.6 Reaction of $^{90}Zr(p,\alpha)^{87}Y$

4.6.1 Experimental Reaction Cross- section for the reaction of $^{90}Zr(p,\alpha)^{87}Y$

The Experimental reaction cross- section of $^{90}Zr(p,\alpha)^{87}Y$ have been published by V.N.Levkovski.He used 15.5 Mev, 16.5 Mev, 17.3 Mev , 18.2 Mev and 19.2 Mev energies for proton projectile.The result obtained were down loaded from EXFOR data center and presented in Table 4.14; below.

Table 4.14: Experimental reaction cross section for the reaction of $^{90}Zr(p,\alpha)^{87}Y$

E(Mev)	$\sigma_{exp.}(mb)$
15.5	1.2
16.5	5.5
17.3	7.5
18.2	8.5
19.2	11.4

4.6.2 Calculated Compound Nucleus Reaction Cross section of($\sigma_{theo.)}$ of $^{90}Zr(p,\alpha)^{87}Y$

The calculation of the compound nucleus reaction cross-section for the reaction of $^{90}Zr(n,\alpha)^{87}Sr$ have been calculated using a nuclear reaction computer code COMPLET. During the choice of data input for the code a proton projectile of energy 15.5 Mev, 16.5 Mev, 17.3 Mev , 18.2 Mev and 19.2 Mev have been selected, the same energy as the experiment as well as the same energy to neutron projectile energy for the calculation was as shown in the Table 4.15 below.

Table 4.15: Calculated reaction cross-section compound nucleus for the reaction of $^{90}Zr(p,\alpha)^{87}Y$

E(Mev)	$\sigma_{theo.}(mb)$
15.5	0.8262
16.5	4.027
17.3	5.794
18.2	6.1404
19.2	7.837

4.6.3 Discussion on the Validity of Calculated Data of $^{90}Zr(p,\alpha)^{87}Y$

For the discussion the validity of calculated compound nucleus reaction cross-section of $^{90}Zr(p,\alpha)^{87}Y$ with its experimental reaction cross-section have been discussed by focusing on Table 4.16 below that arranged from Table 4.14 of section 4.6.1 and Table 4.12 of section 4.6.2

Table 4.16: The difference of reaction cross-section between experimental and calculated compound nucleus of $^{90}Zr(p,\alpha)^{87}Y$

E(Mev)	$\sigma_{exp}(mb)$	$\sigma_{theo}(mb)$	$\Delta\sigma = \sigma_{exp} - \sigma_{theo}(mb)$
15.5	1.2	0.8262	0.3738
16.5	5.5	4.027	1.473
17.3	7.5	5.794	1.106
18.2	8.5	6.1404	2.3596
19.2	11.5	7.837	5.563

As can be seen easily from Table4.16, above the value of the calculated reaction cross-section for the reaction of $^{90}Zr(p,\alpha)^{87}Y$ to its value of experimental reaction cross-section approximately similar.
The result is plotted in the Fig 4.6. This shows the COMPLET code calculation gives a valid result for the reaction in the given energy values.

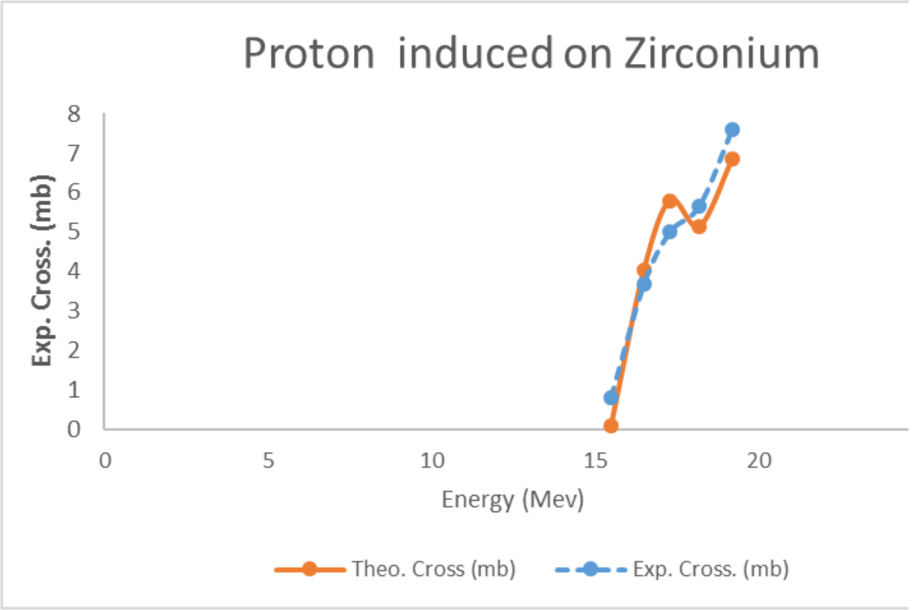

Figure 4.6: Experimental reaction cross-section and theoretical compound reaction cross-section for the reaction of ${}^{90}Zr(p,\alpha)^{87}Y$

4.7 Effect of a Single Electron Charge on the Cross-section of Compound Nuclues in Different Mass Regions.

4.7.1 For Reaction of ${}^{23}Na(n,\alpha)^{20}F$ & ${}^{23}Na(p,\alpha)^{20}Ne$

Compound nucleus cross- section for the two reactions using neutron as a projectile and proton as a projectile for the same energy have been calculated. The result were displayed in Table 4.17. When we view the behavior of the value of the cross-section in Table ,4.17 for 16.8 Mev cross-section for the neutron induced reaction on ${}^{23}Na$ target is 49.79 mb but for the proton induced reaction on the same target and the same energy the reaction cross-

Table 4.17: Effect of a single charge on^{23}Na target

E(Mev)	Calcu.comp.reaction cross section(mb)		
	σ_n	σ_p	$\Delta = \sigma_n - \sigma_p$
16.8	49.79	0.0736	49.7164
18.2	33.89	0.434	33.456

section of the compound nucleus is 0.0736 mb. This shows that the cross-section for a compound nucleus induced by proton projectile in ^{23}Na target is by far less than the cross-section by neutron projectile; Large compound nucleus reaction cross -Section gap have been formed for energy 18.2 Mev as displayed in the table Table4.17. This may be because of the Coulomb's barrier available when the proton projectile approaches the target nucleus reduces the chance of reaction between the projectile and the target nucleus. One electron charge excess carried by the proton projectile suppresses the reaction.

4.7.2 For Reaction of $^{65}Cu(n,\alpha)^{62}Co$ & $^{65}Cu(p,\alpha)^{62}Ni$

Table 4.18: Effect of a single charge on^{65}Cu target

E(Mev)	Calcu.comp.reaction cross section(mb)		
	σ_n	σ_p	$\Delta = \sigma_p - \sigma_n$
6.3	0.0073	29.75	29.7427
9.18	0.67	18.98	18.31
10.1	0.87	14.39	13.52
11	1.06	26.63	25.57

For the two reactions using neutron as a projectile and proton as a projectile for the same energy have been calculated. The result were displayed in Table4.18. When we view the behavior of the value of the cross-section in Table4.18 for projectile energy 6.3 Mev cross-section for the neutron induced reaction on ^{65}Cu target is 0.0073 mb but for the proton induced reaction on the same target and the same energy is 29.75 mb. This shows that the cross-section for a compound nucleus induced by proton projectile on ^{65}Cu target is by far greater than the cross-section by neutron the same energy . In the same manner for the projectile energies 9.18 Mev, 10.1 Mev and 11 Mev the proton induced reaction on target ^{65}Cu have been registered and displaced in the Table 4.18 . The Compound nucleus cross-sections are 18.98 mb, 14.39 mb and 26.63 mb respectively for the proton projectile.But for the case of the neutron induced reaction on ^{65}Cu with the same corresponded energies the reaction cross-section of the compound nucleus is 0.67 mb, 0.87 mb, and 1.06 mb which is much less than the reaction cross-section of the compound nucleus by proton induced reactions.

The difference in the two reactions,the proton charge tends to reduce the chance of reaction during the entrance channel, but the same charge after the formation of the compound nucleus and when the compound nucleus decays by $\alpha-$emission, supports the emission of the $\alpha-$particle.Since the compound nucleus cross-section is the sum of two events,thus the single charge excess during the decay of the compound nucleus supports highly the reaction.

4.7.3 For Reaction of ${}^{90}Zr(n,\alpha){}^{87}Sr$ & ${}^{90}Zr(p,\alpha){}^{87}Y$

Table 4.19: Effect of a single charge on ${}^{87}Zr$ target

E(Mev)	Calcu.comp.reaction cross section(mb)		
	σ_n	σ_p	$\Delta = \sigma_p - \sigma_n$
15.5	2.67	0.8262	-2.1562
16.5	2.973	4.027	12.869
17.3	3.131	5.794	1.054
18.2	3.092	6.1404	2.663
19.2	2.831	7.837	5.006

For the two reactions using neutron as a projectile and proton as a projectile for the same energy have been calculated .The result were displayed in Table4.19,above.

When we view the behavior of the value of the cross-section of the compound nucleus in Table4.19 for projectile energies 15.5 Mev, 16.5 Mev, 17.3 Mev, 18.2 Mev and 19.2 Mev for neutron induced reaction on ${}^{90}Zr$ is 2.67 mb, 2.973 mb, 3.131 mb ,3.092 mb and 2.831 mb respectively.

On the other hand ,when proton induced reaction on ${}^{90}Zr$ cross-section of the compound nucleus for the same corresponded energies were 0.8262 mb, 4.027 mb ,5.794 mb , 6.1404 mb and 7.837 mb as displaced in Table4.19 respectively registered. This implies for all the given energies except at the projectile energy of 15.5 Mev the reaction cross-section of the compound nucleus have been registered by proton induced on ${}^{90}Zr$ target is larger from reaction cross-section of the compound nucleus obtained by neutron induced on the same target and the same energy.

The difference in the two reactions,the proton charge tends to reduce the chance of reaction during the entrance channel, but the same charge after the formation of the compound nucleus and when the compound nucleus decays by $\alpha-$emission, supports the emission of the $\alpha-$particle.Since the compound nucleus cross-section is the sum of two events,thus the single charge excess during the decay of the compound nucleus supports highly the reaction.

4.7.4 Effect of a Single Electron Charge on the Cross-section of Compound Nuclues in Light Mass Region section.

Reactions which use ^{23}Na target have been used as representing in low mass region. Compound nucleus cross-sections for the two reactions using neutron used as projectile and proton is as projectile in the same energy have been calculated and discussed in section 4.7.1. Reaction cross-section of the compound nucleus for neutron induced reaction on ^{23}Na is much greater than reaction cross-section of compound nucleus formed by proton induced reaction on the same target for both 16.8 Mev and 18.2 Mev of energies.
For 16.8 Mev the reaction cross-section have been registered by neutron projectile is larger by 49.7164 mb from reaction cross-section of the compound nucleus formed by proton projectile by the same target and the same energy.In the same manner reaction cross-section of compound nucleus formed by neutron induced reaction for energy 18.2 Mev larger by 33.456 mb from reaction cross-section of compound nucleus formed by proton induced reaction on the same target and with the same energy as neutron projectile displaced in Table4.17 section of 4.7.1 .
From this large gap the effect of a single electron charge on sodium target to be played a negative role for the formation and decay of compound nucleus reaction.Even though,drawing conclusion using a single target ^{23}Na for light mass region is not amenable,this reaction cross- section indicates that the Coulomb's barrier due to one electron charge excess minimizes the reaction by proton projectile to form a compound nucleus.

4.7.5 Effect of a Single Electron Charge on the Cross-section of Compound Nuclues in Intermediate Mass Region section.

As discussed in section4.7.2 ,reaction which used ^{65}Cu target have been used representing as intermediate mass region. The reaction cross - section of the compound nucleus formed by proton induced reaction on^{65}Cu by far larger than reaction cross- section of the compound nucleus formed neutron induced reaction on the same target and the same energy.As can be seen from Table4.18 section of4.7.2 for energies 6.3 Mev, 9.18 Mev, 10.1 Mev and 11Mev the difference reaction cross-section of the compound nucleus reaction induced by proton on target ^{65}Cu from neutron induced on the same target to the corresponding energies were 29.7427 mb, 18.31 mb, 13.52 mb and 25.57 mb registered respectively. The difference in the two reactions,the proton charge tends to reduce the chance of reaction during the entrance channel, but the same charge after the formation of the compound nucleus and when the compound nucleus decays by $\alpha-$emission, supports the emission of the $\alpha-$particle.Since the compound nucleus cross-section is the sum of two events,thus the single charge excess during the decay of the compound nucleus supports highly the reaction.

4.7.6 Effect of a Single Electron Charge on the Cross-section of Compound Nuclues in Heavy Mass Region section.

As discussed in section4.7.3 ,reaction which used ^{90}Zr target have been used representing as heavy mass region . The reaction cross- section of the compound nucleus formed by proton induced reaction on^{90}Zr is greater than from reaction cross- section of the compound nucleus formed by neutron induced reaction on the same target and the same energy except at the projectile energies of 15.5 Mev. As can seen from Table4.19 section of 4.7.3 for energies 15.5 Mev, 16.5 Mev, 17.3 Mev, 18.2 Mev and 19.2 Mev the difference reaction cross-section of the compound nucleus reaction induced by proton on target ^{90}Zr from neutron induced on the same target to the corresponding energies are -2.1562 mb,12.869 mb, 1.054 mb, 2.663 mb and 5.006 mb registered respectively.

The difference in the two reactions,the proton charge tends to reduce the chance of reaction during the entrance channel, but the same charge after the formation of the compound nucleus and when the compound nucleus decays by $\alpha-$emission, supports the emission of the $\alpha-$particle.Since the compound nucleus cross-section is the sum of two events,thus the single charge excess during the decay of the compound nucleus supports highly the reaction.

Chapter 5

Conclusion

This research work have been done for the completion of MSc. degree in physics (Nuclear physics) under the title "The Role of One Proton Charge Excess in the Cross Section for the Formation and Decay of Compound Nucleus by α emission". This was to evaluate the effect of a single charge excess on the formation and decay of compound nucleus reaction of the neutron and proton, $n\&p$, induced reactions with the same target and at the same energy. To achieve the objectives the selected nuclear reactions were $^{23}Na(n,\alpha)^{20}F$, $^{23}Na(p,\alpha)^{20}Ne$ to represent light mass region, $^{65}Cu(n,\alpha)^{62}Co$,$^{65}Cu(p,\alpha)^{62}Ni$ to represent medium mass region, and $^{90}Zr(n,\alpha)^{87}Sr$ & $^{90}Zr(p,\alpha)^{87}Y$ for the higher mass region.

From the research it was concluded that, the coulomb barrier available when the proton projectile approaches the ^{23}Na target nucleus reduces the chance of of reaction between the projectile and the target. This suppresses the reaction cross section for the compound nucleus in light mass region by proton projectile than neutron projectile at the same energy and target. But for the medium and heavy mass region compound nucleus reaction cross section by proton on the same target and the same projectile energy is higher due to the decay of the compound nucleus by alpha particle emission gets supported by the coulomb energy between the residual nucleus and the outgoing particle.

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Appendix

Code Complet

The code COMPLET is a nuclear reactions code which was designed for versatility and ease of use in the bombarding energy range of a few MeV to several hundred MeV. The code COMPLET is based on same philosophy as the former code COMPLEX and an extension of code INDEX. COMPLET code is an extension of the code ALICE-91 and INDEX.These two codes employ the Weisskopf-Ewing model for the statistical part and geometry dependent hybrid model of M.Blann for the pre-equilibrium emission. The code COMPLET gives the result of compound reaction and compound nucleus plus pr-equilibrium reaction. The projectile energy is measured in Mega Electronvolt (MeV) and the cross-section are measured in millibarn(mb).

In COMPLET code a pre-equilibrium process in two stages is assumed.
The particles in the initial configuration($n_o = EX1 + EX2 + EX3$) can be neutron, proton or aplha particle, represented by exciton numbers EX1,Ex2 and Ex3 respectively it is customary to use the initial exciton numbern_o separated into proton and neutron above and holes below the Fermi level as a fit parameter to match theoretical prediction with experimental excitation function. The requirement of detailed input parameters was sacrificed to

achieve this goal.
The code COMPLET provides yields and spectra for all reactions populated by all combinations of n, p, d, and can provide all input parameters internally. The running time of the code is very short. This code includes damping of fission widths above a critical temperature R0. The used code is a further simplification of the formulae due to Paul and Thoennessen in Ann.Rev.Nucl and particle science 44(1944). The code COMPLET includes pre-equilibrium neutron, proton and alpha emission up to two particle, as well as evaporation of neutrons, protons, alphas, deuterons, tritons and hellions.

Originally, this code has been developed out of the code OVERLAID ALICE by M.Blann, while some standard routines remained practically unchanged (like FISROT, LYMASS, PUNCH, PLT, PARAP, OVER1, OVER2 and TLJ) others have been substantially modified (like MAIN, SHAFT, NUCMFP, etc) or are completely new (like, INDEX, PARDEN, TRAPRO, ANGULAR, etc) the underlying PE-MODEL is described in Z.Phys.A328 (1989).It is contained in subroutine INDEX.

The INPUT is described below. The notion card from the old FORTRAN input is still kept but now corresponds to lines. Free formats, the input values should be separated by , or CR.

CARD 1 - GENERAL INPUT DATA

- AP projectile mass number
- AT projectile charge
- ZT Target charge

QVAL Reaction Q value = AP + AT - ACN
=0: calculated from M and S mass formula.
= 1: calculated from mass excesses of 1990 nuclear wallet cards.

PLD Level Density Parameter a, a = CAN/PLD. = 0: a = CAN/8

CLD Ratio of single particle level densities AF/AN = 0: AF/AN = 1.0

BARFAC Multiplies the rotating drop fission barrier by this value. = 0: BARFAC= 1

ROTFAC Multiplies the rotational energy by this value. $= 0:$ ROTFAC= 1.

RO Critical temperature above onset of retarded fission

GI Nuclear friction parameter from equilibrium deformation to saddle

GO Nuclear friction parameter from saddle to scission point

NA Number of nuclides of each Z to be included in calculation. Up to 21 neutrons may be emitted (Maximum NA=22)

NZ Number of Z- values to be calculated in the emission process. Up to8 protons may be emitted (Maximum NZ=9).

For correct PE calculations binding energies are calculated for all nuclei with $Iz, IA \leq 5$

MC Shell correction option for masses subroutine.

- = 0, Shell correction.
- = 1, No shell correction
- = 2, BE values will be supplied as input.
- > 2, BE values are calculated from 1990 nuclear wallet cards.

MP Pairing correction to masses.

- = 0: No correction
- = 1: pairing term item =2: masses are from nuclear wallet cards;
- =3: pairing correction in masses, NOTE: changes are not corrections in only level densities

IPA Pairing corrections in level densities

- IP= -1, No corrections
- IP =0, standard correction i.e multiplier =12
- If $IPA > 0$ multiplier is IPA

M3 Number and type of particles to be emitted from each nuclide

If = 1: N only;= 2:N and P;=3 or =0:N,P and Alpha;=4:N,P,

Alpha and Deuteron = 5: N, P, Alpha, Deuteron and Triton;=6: N,P, Alpha, Deuteron, Triton and hellion (3He); =7: as before includes Gammas.Calculations until gamma emission is finished, important for isomeric ratio calculations.

INVER Inverse cross section

parameter = 0: user will supply; =1: results by O.M subroutines asALICE/85/300,

If = 2 O.M for N, p as in old ALICE; If =3: sharp cutoff values forinverse cross sections.

IKE

If = 1 No particle spectra will be printed;

If= 2 Equilibrium spectra for each nuclide will be printed;

If =3: Only pre-compound spectra will be printed;

If = 5: PE and summed equilibrium spectra will be (separately) printed;

If =4 AS 2+3

If IKE = -2 to -5: reduced output with spectra IKE =ABS(IKE)(yields are printed after negative energy input)

If $IKE \leqslant 0$ or $IKE = 6$most reduced output

IPCH

= 1: inverse cross sections will be readout for possible future use in separate output file.

= 0: or NE from 1, No printout

KPLT Number of decades to be plotted as excitation function on line printer.

If KPLT = 0: no plotting

CARD 2 TITLE CARD

If MC = 2 on CARD 1, read user supplied n, p, alpha, deuteron, triton and helion binding

energies here, Format for IA =1 to NA, IZ=1 to NZ. If INVER =0 on CARD1, read n, p, alpha, deuteron, triton, helion and gamma inverse cross sections here. In

ascending

channel energy, first value = 0.1 MeV, incremented by 1MeV, 48 values per particle type

in sequence N,P,A,D,T,3HE, and Gamma depending on value of M3.

CARD 3 ENERGY and CN & PE OPTIONS

IKEN projectile kinetic energy in the laboratory system.

If = 0: A new problem will begin at CARD1.

If < 0: previously calculated excitation functions will be printed (if not KPLT=0,

EKIN values were run in ascending order they are plotted).If EKIN=0 on two

successive

cards, a normal exit will occur for negative target mass on card 1.

RCSS = 0: Reaction cross section is calculated from subroutine (for pi-induced

reactions: if RCSS (input) =0, RCSS=100 mb) if input> 0: number of T(l) values to be read from the next card

JCAL Types of calculation options

= 1, weisskopf-ewing evaporation calculation

= 2, S- wave approximation, liquid drop moment of inertia,

= 3, S- wave with rigid body,

= 0, Calculation for all partial wave including fission and full angular momentum coupling up to DELTA L=12.

JFRAC Direct- semidirect capture gamma ray estimate :$<$ 0: no emission,$>$ 0: approach of kalka, =0 simple approach with initial exciton-number = 1 for P,N.

JANG JANG + 1 = maximum number of contributing incoming partial waves. Usually use the maximum: JANG =99. Otherwise, JANG can be used for cutoff on L values provided by subroutines OVER1 and 2

All additional parameters on this card are for the pre-compound calculation options. Put TD-values to zero, if no pre-compound calculation is wanted.

TD Initial exciton number =p+h

EX1 Initial excited neutron number

EX2	Initial excited proton number
EX3	Initial alpha particle exciton number

POT Fermi energy in Mev

If = 0: POT is calculate from nucl.matter value= 37.8 Mev;

AV If = 0: OPTICAL MODEL mean free paths are used in routine MFP.

Not to be used above 55 Mev.

If AV = 1: Nucleon-Nucleon mean free paths are used in NUCMFP.

ALF Probability that newly created exciton particle from first stage exciton gets

an alpha particle in the second stage.

(1-ALF): complementary probability

If ALF > 1 calculation for two initial exiton numbers

A) ATD=TD-3 (min.1.5) AEX1=AEX2=0. AEX3=2;ATD=TD-6 for TD > 9

with weight ULF=INT (ALF)100

B)Weight = (1-ULF), with initial exciton numbers.

CMFP Mean Free Paths are multiplied by CMFP.if CMFP =0:multiplier is 1 GDO Critical angular momentum.

GDO > 0: partial waves with L $> GDO$ are not taken in to account in the (second) line of isotone cross sections while cross sections for partial waves with $L > GDO$ are

accounted for in the (third) line below N.B For $GDO + 0$:5 No cut-off.

CARD 4 ENERGY AND REACTION CROSS SECTION

EKIN	Projectile kinetic energy in the laboratory system

This card is repeated for each energy wanted in calculating excitation function

with parameters specified in card 1 and card 3.

RCSS As on card 3

CARD 5 ISOBARIC YIELD CALCULATIONS IN EXCITATION FUNCTIONS

(Card 5 is read after negative energy on card 4 or 3)

and INDEX. ISOBA 28 numbers are expected since maximum 28 isobaric chains exist starting

from CAN-1. The 28 ISOBA inputs may vary from 0 to 9 according to the number of

ISOBARS to be added.

JIMMA UNIVERSITY
COLLEGE OF NATURAL SCIENCES
PERFORMANCE CERTIFICATE FOR MASTER'S DEGREE

Name of Student: **Negash Ahmed** ID No. **RM 1199/09**

Graduate Program: **Regular, MSc.**

1. Course Work Performance

Course Code	Course Title	Cr. hr	Number Grade	Rank **	Remark
Phys799	**MSc. Thesis**	**6**			

** Ecellent, Very Good, Good, Satisfactory, Fail.

Thesis Title

The Role of One Proton Charge Excess in the Cross-section for the Formation and Decay of Compound Nucleus by Alpha Emission

2. Board of Examiners decision Mark × in one of the boxes. Pass ☒ Failed ☐

If failed, give reasons and indicate plans for re-examination.

____

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3. Approved by: Name and Signature of members of the examining Board, and Deans, SGS

Committee member	Name	Signature	Date
Chairman	________________	________________	________________

External Examiner ________________ ________________ ________________

Internal Examiner ________________ ________________ ________________

Major Advisor ________________ ________________ ________________

________________________________ ________________ ________________

Dean, School of Graduate Studies(SGS) Signature Date

School of Graduate Studies
Jimma University
College of Natural Sciences
MSc. Thesis Approval Sheet

We the undersigned, number of the Board of Examiners of the final open defense by **Negash Ahmed** have read and evaluated his/her thesis entitled "**The Role of One Proton Charge Excess in the Cross-section for the Formation and Decay of Compound Nucleus by Alpha Emission**" and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree Master of Science in **Physics (Nuclear Physics)**.

Name of the Chairperson	Signature	Date
Name of Major Advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date

SCHOOL OF GRADUATE STUDIES