
# Excitation Function of Charge Transfer Reaction in Different Nuclear Mass Region

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**January, 2019**

DECLARATION

I hereby declare that this Msc thesis paper is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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# Excitation Function of Charge Transfer Reaction in Different Nuclear Mass Region

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# Abstract

In this thesis we have studied excitation function of charge transfer reaction in different nuclear mass region. In the study, calculations of the excitation function of ${}^{23}_{11}Na(p,n){}^{23}_{12}Mg$,${}^{23}_{11}Na(n,p){}^{23}_{10}Ne$, ${}^{50}_{27}Co(p,n){}^{59}_{28}Ni$,${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$, ${}^{197}_{79}Au(p,n){}^{197}_{80}Hg, and$ ${}^{197}_{79}Au(n,p){}^{197}_{78}Pt$ reactions have been carried out which are selected in different nuclear mass regions. In these calculations the total cross section for each as a function of energy have been obtained. The calculations were done using ALICE-91 based computer code, and exciton model. The calculated results have been compared with experimental data taken from data EXFOR library. Comparison of the experimentally measured values and calculated values show that total cross section varies with respect to the projectile energy, target mass and different parameters. Charge transfer reaction using exciton model gives data which are nearer to the experimental data given in literatures.

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# 1

# Introduction

## 1.1 Back Ground of the Study

Nuclear reaction cross section deals about the probability of the occurrence of a particular type of reaction during nuclear interaction. The study of the cross section of nuclear reaction gives many basic information about that particular type of reaction.Hence having good idea or knowledge of the cross section of a nuclear reaction leads to better conclusion about that reaction. Charge transfer is a fundamental process in nuclear physics which has been studied in various contexts for a long time. During the last decade, it has received renewed attention, when the discovery of cometary X-ray emission revealed that this process can be an important source of X-ray emission, which was overlooked before. In most of the charge transfer reactions (charge of one electron is transferred between the projectile and target), cross sections are studied experimentally in different literatures [1] . The cross section of these type of reactions depend on the target mass, projectile energy, and other quantum states of the interacting system. Therefore, the theoretical study of the dependence of the cross section of charge transfer reactions as a func-

tion of target mass and projectile energy is the main concern of this research. The study of nuclear reaction 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 reaction are of value any chemist who wishes a deeper insight in to chemical reactions. There are certain nuclear reactions that play the basic role in the affairs of man and our understanding of the natural world in which we live [2,3,4]. 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 important would be enough to justify their study. Target nuclei categorized into three nuclear mass region as follows:[5]

- lighter nuclei: $1 \leq A < 25$.
- Intermediate nuclei: $25 \leq A < 80$.
- Heavy nuclei : $80 \leq A < 240$ .

## 1.2 Statement of the Problem

Excitation function of the charge transfer reactions can be used as a tool to study the early stages of the reaction. Theoretical study of the different properties of charge

transfer reactions gives a better insight and understanding on the process of the intermediate stage than experiments. When we observe different literatures there was the experimentally measured values, but we have not seen theoretically calculated total cross sectional value for these reaction on these energy interval. We made an effort to obtain the cross-sections using a computational method. The results were compared with experimental data cross-sections. The influence of the different nuclear mass on the target and excitation functions were studied in the charge transfer reactions.

To study the excitation function of charge transfer reaction, in this work to investigates charge transfer reactions in the different nuclear mass region of the following reactions were considered.

- In light nuclear mass region ${}^{23}_{11}Na(p,n){}^{23}_{12}Mg$ and ${}^{23}_{11}Na(n,p){}^{23}_{10}Ne$ reactions in the energy range 6.3-10.75MeV.
- In medium nuclear mass region ${}^{59}_{27}Co(p,n){}^{59}_{28}Ni$ and ${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$ reactions in the energy range 8-13.83MeV. and
- In heavy nuclear mass region ${}^{197}_{79}Au(p,n){}^{197}_{80}Hg$ and ${}^{197}_{79}Au(n,p){}^{197}_{78}Pt$ reactions in the energy range 13.4-18.15MeV.

while calculating the cross section of each of the above reactions, this research will answer the following leading questions.

- What are the theoretical values of the total cross section for the six reactions?
- What agreement is there between the calculated values of cross section and

experimentally measured values?

- How is the response of the cross section of the charge transfer reactions as a function of projectile energies?

## 1.3 Objectives

### 1.3.1 General Objective

The general objective of this research was:

♣ To calculate excitation function of some of the charge transfer reactions in different nuclear mass region.

### 1.3.2 Specific Objectives

The specific objectives of the study are:

- To calculate the theoretical values of the total cross section for the reactions described in section 1.2.
- To discuss the agreement between the calculated values of cross section and experimentally measured values.
- To explain the response of the cross section of the charge transfer reactions as a function of projectile energies.
- To discus dependence of cross section of charge transfer reaction on projectile energy in different mass regions.

## 1.4 Significance of the Study

This research will have the following advantage:

- The study contributes to the calculation of nuclear reaction cross section of charge transfer reactions mentioned in section 1.2.
- It can be considered as an effort to modify the nuclear reaction code depending on how the calculated result agrees with experiment.
- It gives a theoretically calculated data on the charge transfer reactions mentioned in section 1.2.
- It provides an information on how the(p,n)and(n,p)reaction probabilities depend on projectile energy in different mass regions.
- The output of this research work may be used as a reference for other studies.

# 2

# Literature Review

## 2.1 Nuclear Reaction

Nuclear reactions and nuclear scattering are used to measure the properties of nuclei [6]. Reactions that exchange energy or nucleons can be used to measure the energies of binding and excitation, quantum numbers of energy levels, and transition rates between levels [2,4]. A particle accelerator which produces a beam of high-velocity charged particles (electrons, protons, alphas,or "heavy ions"), creates these reactions when they strike 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. Beams of photons, mesons, muons, and neutrinos can also produce nuclear reactions [7,8]. 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. A nuclear reaction is described by identifying the incident particle, target nucleus, and reaction products [9,10].

## 2.2 Reaction Mechanisms

An incident particle,such as a nucleon, may enter and leave the nucleus at different angles,but with the same energy(elastic scattering)[11,12]. The nucleon may collide directly with a nucleon of the nucleus; in this case, if either or both of the nucleons have an energy greater than that required to leave the nucleus, they may leave without interacting with any of its other nucleons (direct process)[6]. There also exist more complex direct reactions, in which the energy of the incident particle is transferred directly to one nucleon or a small group of nucleons in the nucleus. If the energy introduced by the incoming particle is gradually distributed among many nucleons of the nucleus, the nuclear states will become increasingly more complex. However, after a certain time, dynamic equilibrium will be reached: deferent nuclear configurations will arise and decay in the resultant system, called a compound nucleus. The compound nucleus is unstable and rapidly decays into the final products of the nuclear reaction. If the energy of one of the nucleons in some

configurations is sufficient for ejection from the nucleus, the compound nucleus decays with the emission of a nucleon [13,14]. On the other hand, if the energy is concentrated in a few groups of particles, existing for a short time in the compound nucleus, then there may be the emission of alpha particles, triton, deuteron, and the like. At excitation energies of the compound nucleus that are lower than the energy for the ejection of particles, the only reaction path is the emission of gamma quanta. Sometimes particles are ejected before equilibrium is reached, that is, before the formation of a compound nucleus (the mechanism of pre-equilibrium decay). At low energies of the incident particles, the major mechanism of nuclear reactions, as a rule, is the formation of a compound nucleus, with the exception of nuclear reactions with deuteron. Direct processes predominate at high energies [15]. The nature of the dependence of the effective cross sections $\sigma$ of nuclear reactions on the energy $\epsilon$ of the incident particles $\sigma(\epsilon)$ differs for different mechanisms of nuclear reactions. For direct processes, the dependence $\sigma(\epsilon)$ exhibits monotonic behavior. In the case of nuclear reactions resulting in the formation of compound nuclei, maxima are observed in $\sigma(\epsilon)$ at low particle energies; these maxima correspond to the energy levels of the compound nucleus. In the high energy region ($\epsilon \geq 15$ MeV for intermediate mass and heavy nuclei), the energy levels of the compound nucleus overlap, and the cross section depends monotonically on energy. The energy spectrum of the decay products of a compound nucleus in the region of higher energies consists of separate lines, and in the low energy region the emitted particles have a broad maximum. In order to write an equation for a nuclear reaction, we must first establish some basic rules. Each of the elements involved in the

reaction is identified by the chemical symbol and two numbers are attached to the symbol. One of them is the mass number, also known as the 'A' number [10]. The 'A' number describes the atomic weight of the atom and identifies the number of protons and neutrons in the nucleus. The second number is the atomic number, or 'Z' number. The 'Z' number describes the number of protons in the nucleus and determines the type of atom. 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.

$a + X \rightarrow b + Y$ or $X(a,b)Y$ 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).

Based up on mechanism of interaction there are a number of nuclear reaction **Elastic scattering**: the target and the projectile remain unchanged after interaction. No energy is transfers in to nuclear excitation. Momentum and kinetic energy of the system is conserved (both momentum and kinetic energy is conserved)[11]. The initial quantum mechanical state(energy, angular momentum, linear momentum ... etc)is unchanged. In reaction formula elastic scattering is,

X(x ,x )X .

**Inelastic Scattering**: a reaction in which the enterance channel and the outgoing channel contains the same particles with different energy. The target nucleus gains energy of excitation from the projectile and becomes in the excited state. In inelastic

scattering momentum is conserved, but kinetic energy is not conserved. The target nucleus x goes to exited state x*. The excited state may come down to initial state by emitting prompt radiation.

- $X(x,x)X*$.

- $X^* \rightarrow$ x + $\gamma(prompt)$.

**Charge Transfer Reaction**: In a charge exchange reaction both energy and charge are exchanged between the projectile and the target nucleus. The most important charge exchange reactions are the (p,n) and the (n,p) reactions. Both provide useful information on nuclear reaction. The cross-sections for the former are one order of magnitude greater than the latter [3]. However, the(p,n)reactions occur throughout the nuclear volume while the (n,p)reaction is confined to the nucleus surface since both and easily dissolve into their constituents in their passage through the nuclear interior. In such a charge exchange process the target nucleus is converted into an isobar [10]. That the isospin is a good quantum number is evidenced by the parity of the isobaric analogue state excited in the high resolution measurements of (n,p)reactions. Neutron-proton charge exchange differential cross sections have been measured at high energies. In its basic principle, charge transfer is a very simple process: charge (in the form of one or more electrons) is transferred from an atom or molecule to an ion that gets into an excited state, from which it may de-excite by releasing electromagnetic radiation. If the initial charge of the ion was sufficiently high, then the energy of the radiation can be in the X-ray range. The main characteristics of charge transfer are a very high cross section (of the order of

$10^{-15}cm^2$) and characteristic line emission at X-ray energies and below. Despite its apparent simplicity, however, a detailed understanding of this fundamental process is a most challenging task. A detailed theoretical description of charge transfer is so challenging that several approximative techniques have been developed.

### 2.2.1 Direct Nuclear Reactions

These are particularly useful in experimental nuclear physics, because the reaction mechanisms are often simple enough to calculate with sufficient accuracy to probe the structure of the target nucleus. To qualify as a direct reaction, both the target nucleus and the internal structure of the cluster transferred must be undisturbed by the reaction.The residual nucleus is simply the coupled product of the cluster and the ground state of the target nucleus [7,10,16]. This condition is generally difficult to meet for transfer reaction involving large numbers of nucleons. The reaction proceeds directly from the entrance channel to the exit channel without the formation of an intermediate state(short glancing collision). If the internal states of the colliding systems do not change, we have elastic scattering. If one or both systems are excited in the exit channel, we have inelastic scattering If one or more nucleons are transferred from one nucleus to the other, we have a transfer reaction. If a nucleon or light nucleus is ejected from the target while the projectile continues free, we have quasi-elastic scattering [17]. The stripping and pick up reactions are interactions with surface nucleons (few nucleons), are examples of direct reactions which take place at the higher energies. In such reactions the projectile picks up a nucleon from target nucleus and sometimes the projectile is stripped off a nucleon

by the target nucleus.

- ${}^{2}_{1}H + {}^{63}_{29}Cu \rightarrow {}^{64}_{29}Cu + {}^{1}_{1}H$ Stripping off process
- ${}^{1}_{1}H + {}^{27}_{13}Al \rightarrow {}^{27}_{13}Al + {}^{2}_{1}H$ pick-up process

### 2.2.2 Compound Nucleus Formation

Compound nucleus formation is a reaction in which two nuclei combine into a single excited nucleus; the excited nucleus lives for a relatively long time and ”forgets” how it was formed [8,18]. The decay from this state of excitation is by ”evaporation” of nucleons from the heated liquid drop of the compound nucleus, by gamma decay, or by fission of the compound nucleus. The statistical nature of this process teaches us about the average properties of excited states of complex nuclei. Multi fragmentation reactions, in which high energy nuclei collide with other nuclei, are a method of creating nuclear matter in unusual conditions of density and excitation energy. These states may be in a different phase from normal nuclei and be characteristic of the matter in the early universe [13]. When nucleons are flung at one another, they can mesh briefly. During the time they are one nucleus, the quarks in the nucleons can interact with one another as if they were free particles. As with Rutherford scattering, an investigation of the angle that a particle is scattered gives information about the conditions inside the nucleons. Nuclear reactions and their interpretation are the main activity of most nuclear scientists.The continuing development of accelerators and detectors permit the refinement of nuclear data and

models to benefit basic science and nuclear applications.

For example

- ${}^{4}_{2}H + {}^{23}_{11}Na \rightarrow {}^{27}_{13}Al$
- ${}^{14}_{7}N + {}^{6}_{3}Li \rightarrow {}^{20}_{10}Ne$ .

The compound nucleus forgets the history of formation. Hence, it doesn't remember how it was formed (what was the entering projectile and what energy $E$. The compound nucleus is excited to an energy states with; $E = \epsilon_\alpha + S_a$ Where E- is the total excitation energy of the compound system, $\epsilon_\alpha$-is kinetic energy of the projectile, $S_a$-Separation energy [5,19]. The compound nucleus has lifetime $\sim 10^{-16}$ second and it will decay into deferent channel but it will depend only on the energy of excitation, angular momentum and parity. The decay will not depend upon the mode of formation of compound nucleus. It will depend only on the Quantum mechanical parameters of state (Energy, angular momentum etc). The compound nucleus can be described by statistical mechanics as being in a state of statistical equilibrium. The energy distribution of the components of the system is given by a Maxwellian distribution. A component of this system may receive a large amount of energy as the result of a statistical fluctuation. In the case of charged particles, this minimum energy is the Coulomb barrier of the compound nucleus. When the compound nucleus has reached statistical equilibrium, we say that it has been thermalize.

### 2.2.3 Pre-equilibrium Reactions

Pre equilibrium reaction is neither direct nor compound nuclear reaction but in some conditions it is possible for particles to be emitted after the first stage of a nuclear interactions but before the attainment of statistical equilibrium or compound nucleus formation. In pre-equilibrium reactions, the emission of particles from the excited target nucleus is neither by statistical decay of the compound nucleus nor by the prompt emission after collision [5,16]. The emission of a particle by the target nucleus happens neither immediately after the collision nor by the statistical decay of the compound nucleus. The projectile shares its energy among a small number of nucleons in the target. The struck nucleons initiate a cascade of reactions within the target, at the course of which a particle can be emitted (before the compound nucleus has reached a state of statistical equilibrium). It is now well known that the separation of nuclear reaction mechanisms into direct and compound is too simplistic [20]. The cross section as predicted by the pure compound process is too small with respect to measured continuum spectra and the direct processes described in the previous section only excite the discrete levels at the highest outgoing energies. Furthermore, the measured angular distributions in the region between direct and compound are anisotropic, indicating the existence of a memory-preserving, direct-like reaction process. Apparently, as an intermediate between the two extremes, there exists a reaction type that embodies both direct and compound like features. These reactions are referred to as pre-equilibrium, pre compound or, when discussed in a quantum mechanical context, multi-step

processes. Pre-equilibrium emission takes place after the first stage of the reaction but long before statistical equilibrium of the compound nucleus is attained. It is imagined that the incident particle step-by-step creates more complex states in the compound system and gradually loses its memory of the initial energy and direction. Pre-equilibrium processes cover a sizable part of the reaction cross section for incident energies between 10 and (at least) 200 MeV. Pre-equilibrium reactions have been modeled both classically and quantum mechanically and both are included in TALYS [21]. There are different types of pre-compound nuclear reaction models. These are:

- Exciton model
- Hybrid/geometry dependent hybrid (GDH) Models.
- Harp-Miller-Bern (HMB) model
- Intra-nuclear cascade (INC) Model

**Exciton Model**

In the exciton model [22, 23, 24] the nuclear state is characterized at any moment during the reaction by the total energy$E_{tot}$ and the total number of particles above and holes below the Fermi surface. Particles ($p$) and holes($h$) are indiscriminately referred to as excitons.Further more, it is assumed that all possible ways of sharing the excitation energy between different particle-hole configurations with the same exciton number $n = p + h$ have equal a priori probability. To keep track of the evolution of the scattering process, one merely traces the temporal development

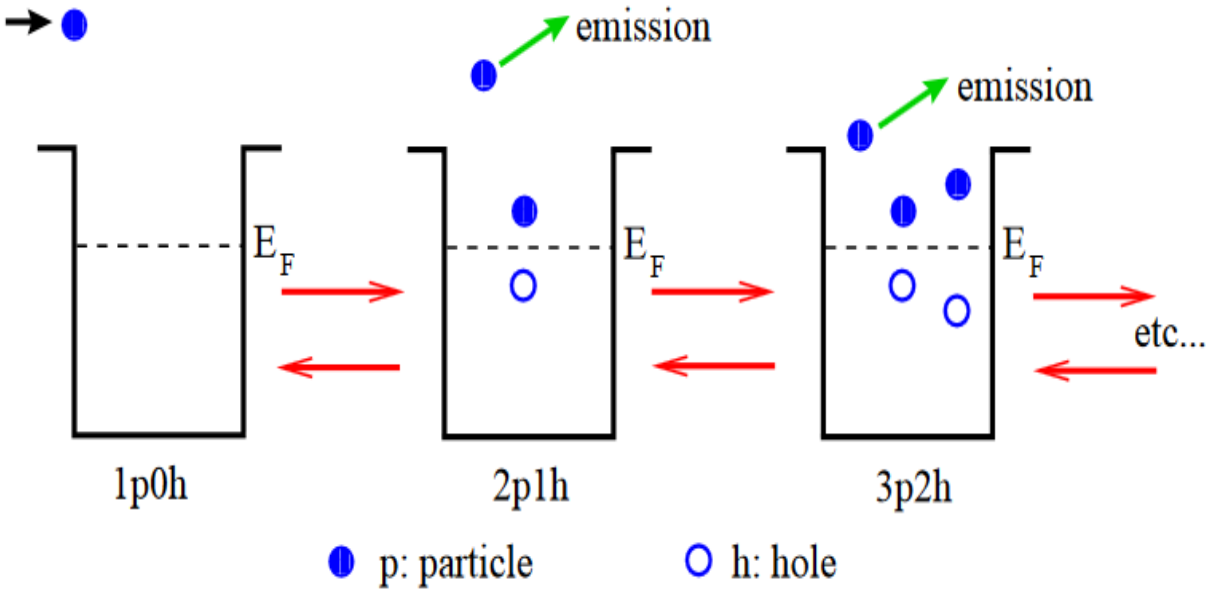


Figure 2.1: Reaction flow in exciton model

of the exciton number, which changes in time as a result of intranuclear two body collisions. The basic starting point of the exciton model is time dependent master equation, which describes the probability of transitions to more and less complex particle-hole states as well as transitions to the continuum (emission)[22,25]. Qualitatively, the equilibration process of the excited nucleus is imagined to proceed as Figure 2.1. After entering the target nucleus, the incident particle collides with one of the nucleons of the Fermi sea, with depth $E_F$. The formed state with $n = 3(2p1h)$, in the case of a nucleon induced reaction, is the first that is subject to particle emission, confirming the picture of the exciton model as a compound like model rather than a direct like model[9]. Two-component exciton model In the following reaction equations,we use a notation in which $p_\pi(p_\upsilon)$ is the proton (neutron) particle number and $h_\pi(h_\upsilon)$ the proton (neutron) hole number.From this, we define the proton exciton number $n_\pi = P_\pi + h_\pi$ and the neutron exciton number $n_\upsilon = p_\nu + h_\upsilon$.

From this, we can construct the charge independent particle number $p = p_\pi + p_\upsilon$, the hole number $h = h_\pi + h_\nu$ and the exciton number $n = n_\pi + n_\upsilon$. Particle emission only occurs from n = 3(2plh) and higher exciton states[20]. For the single particle state densities we take $g_n = Z/15, g_\upsilon = N/15$, which is, through the relationship $g = a\pi^2/6$, in line with the values for our total level density parameter a, and also provides a globally better description of spectra than the generally adopted g = A/13.

## 2.3 Cross Section

cross-section is the effective area of nucleus as seen by a projectile is termed as the nuclear cross -section. It represents probability of a given type of nuclear reaction taking place. It is measured in terms of number of events procedure by a definite number of projectiles per nuclei. It can be measured in terms of number of absorbed projectile[11,16]. Nuclear cross-section is symbolically represented by a Greek letter sigma $(\sigma)$. The quantity $\sigma_r$ is better named the partial cross-section for a particular reaction $'r'$. In a typical scattering experiment, a beam of particles is allowed to hit a target and the rates of production of various particles in the final state are counted. It is clear that the rate will be proportional to: (a) the number N of particles in the target illuminated by the beam, and (b) the rate per unit area at which beam particles cross a small surface placed in the beam at rest with respect to the target and perpendicular to the beam direction. The latter is called the flux and is given by [2,20]

$$J = n_b v_i \tag{2.1}$$

Where $n_b$ is the number density of particles in the beam and $v_i$their velocity in the rest frame of the target. Hence the rate $w_r$ at which a specific reaction r occurs in a particular experiment can be written in the form

$$W_r = JN\sigma_r \tag{2.2}$$

Where $\sigma_r$, the constant of proportionality, is called the cross-section for reaction r. If the beam has a cross-sectional area A, its intensity is I=JA and so an alternative expression for the rate is[21]

$$W_r = \frac{JN\sigma_r}{A} = I\sigma_r n_t \tag{2.3}$$

Where $n_t$ is the number of target particles per unit volume and t is the thickness of the target. It can be seen from the above equations that the cross-section has the dimensions of an area(A); the rate per target particle $J\sigma_r$ at which the reaction occurs is equal to the rate at which beam particles would hit a surface of area $\sigma_r$ , placed in the beam at rest with respect to the target and perpendicular to the beam direction. The quantity $\sigma_r$ is better named the partial cross-section, because it is the cross-section for a particular reaction r. The total cross-section$\sigma$ is defined by

$$\sigma_= \sum \sigma_r \tag{2.4}$$

## 2.4 Differential Cross-section

The quantity $d\sigma/d\Omega$ is called the differential cross section and its measurement gives us important information on the angular distribution of the reaction products [7]. Solid angle is measured in steradian (the surface of a sphere subtends a solid angle

of $4\pi$ steradian at its center ). Detector occupies only a small solid angle $d\sigma$ and therefore does not observe all of the outgoing particle;only a fraction of the cross section $d\sigma$ will be deduced. Moreover, the outgoing particles will not in general be emitted uniformly in all directions,but will have an angular distribution that will depend on $\theta$ and possibly also on $\phi$. A beam of particles is incident along the Z-axis and collides with a stationary target at the origin; the differential cross-section is proportional to the rate for particles to be scattered in to a small solid angle$d\Omega$in the direction$(\theta, \phi)$ [11,24].

$$d\sigma/d\Omega = r\frac{(\theta,\phi)}{4\pi I_a N} \tag{2.5}$$

The reaction cross section $\sigma$ can be found by integration $d\sigma/d\Omega$ over all angles: with $d\sigma = \sin\theta d\theta d\phi$

$$\sigma = \int d\sigma/d\Omega d\sigma = \int_0^{\pi} \sin\theta d\theta \int_0^{2\pi} d\phi d\sigma/d\Omega \tag{2.6}$$

## 2.5 Quantum Mechanical Considerations of Cross-sections

Classical formulae are generally only useful when the de Broglie wave length $\lambda$ small compared with the nuclear size (or interaction radius). When $\lambda$ is comparable with or greater than R,quantum effects become important;a proper trajectory cannot be defined and the simple relationship between the geometric cross section, impact parameter and angular momentum break down [10]. The interaction region by approaching projectile is divided into a set of ring shaped zones concentric with the head-on collision point. The zones are labeled by the orbital angular momentum quantum number *l*. The inner most $(l = 0)$ zone correspond to particles with im-

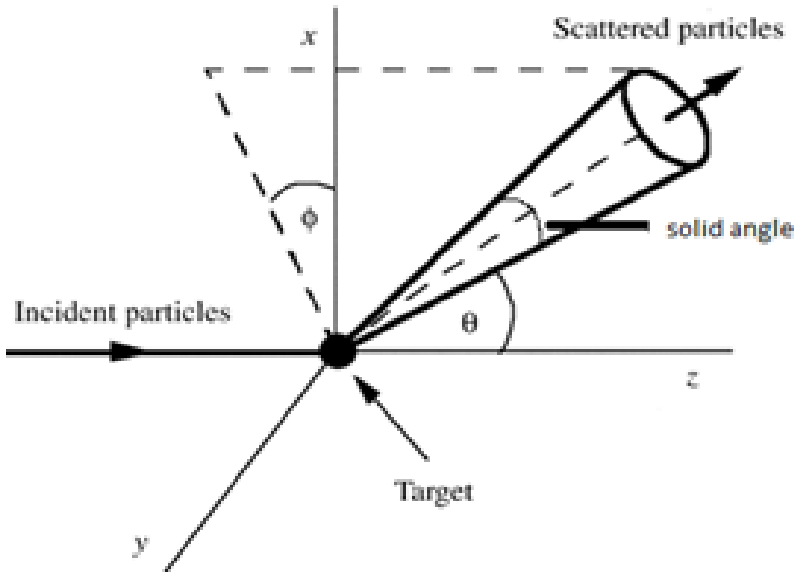


Figure 2.2: A particle incident on a thin slice of matter contains *n* scatters per unit volume of cross section $\sigma$ [12]

pact parameter less than the reduced wavelength ($\hbar = \frac{\lambda}{2\pi}$) of the beam particles, the next includes impact parameters between $\hbar$ and $2\hbar$and so on. Impact parameters for the $l^{th}$ zone range from $l\hbar$to $(l+1)\hbar$ and correspond, classically, to particles with momentum p having angular momenta between $pl\hbar$, i. e. between $pl\hbar$ and$p(l+1)\hbar$. In quantum mechanics, only integral value of *l* are allowed and,although the concept of impact parameter is imprecise, we interpret this picture to say that particles with angular momentum $l$ correspond to the $l^{th}$zone. In this way, a plane wave, representing a parallel beam, can be split in to a set of partial waves, or*l* waves, each associated with a particular zone and partial wave cross-section *l*. The cross-sectional area of the$l^{th}$zone is

$$\sigma = (2l+1)\pi\hbar^2 \tag{2.7}$$

It represents an upper limit to the total reaction cross section. Since no more par-

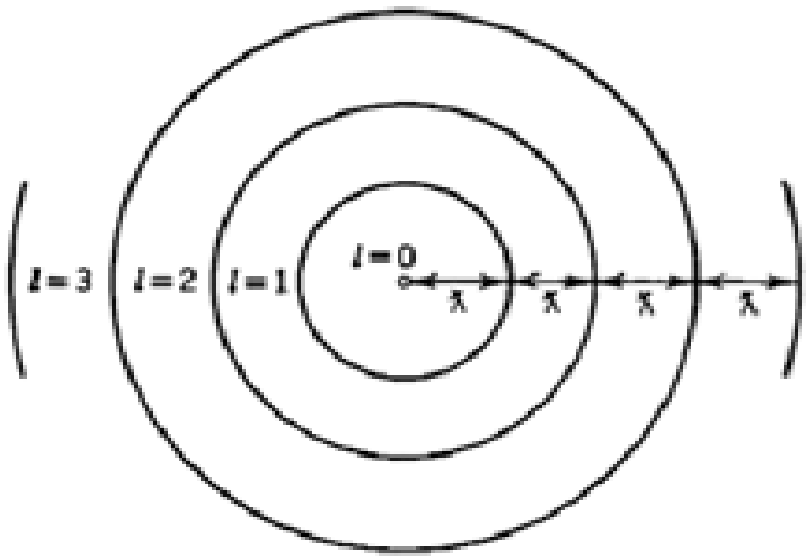


Figure 2.3: The incident beam is directly perpendicular to the plane of the figure. The particles with a given $l$ hit predominantly the indicate ring-shaped areas [10]

ticles can be taken out of the beam than in it originally, we expect that the reaction cross section $\sigma_{(r,l)}$ cannot be larger than this amount. Hence, the reaction cross section for the $l^{th}$ partial wave is

$$\sigma \leq (2l+1)\pi\hbar^2 \tag{2.8}$$

It does not apply to the elastic scattering cross section. Expanding the cross section in to partial waves is most useful when we are dealing with low energy collisions and the wavelength is comparable with the nuclear size. As the value of $l$increases above zero, the overlap of the $l^{th}$ zone with nucleus decreases and soon reaches the point where the effect of the nuclear interaction on the partial wave becomes negligibly small. Thus, we expect that only a few partial waves with $\leq \frac{2\pi R}{\lambda}$ need to be taken in to account in any analysis of the nuclear reactions that take place. In an extreme

case, such as slow neutron induced reactions, we have$\lambda \gg R$ and only the $l = 0$ we need be considered.

## 2.6 Scattering and Reaction Cross sections

In a given interaction center there may be many event. We divided the events in to two main parts: Elastic scattering(sc) and Reaction(r). We include the various inelastic scattering cross section in reaction cross section.

### 2.6.1 Scattering Cross Section

Consider a z-direction plane wave incident on a nucleus.

The wave function for the incident plane wave:

$$\psi_{inc} = A \exp^{ikz} \tag{2.9}$$

In a region of space where is no potential (or a constant potential). since no potential is also a central potential (in the sense that it does not depend on orientation), the solution in spherical polar coordinates,and identify the angular momentum components of the incident wave [10]. Then

$$\psi_{inc} = A \exp^{ikz} = \sum_{l=0}^{\infty} i^l (2l+1) jl(kr) P_l(\cos\theta) \tag{2.10}$$

Where $ji's$ are the spherical Bessel functions, and the $Pi's$ are the regular Legendry polynomials. Consider the mathematical representation of the wave at locations far from the scattering center. Thus, for $kr >> 1$ and by using the asymptotic properties of$ji's$function.

$$\lim(jk) = \frac{sin(kr - l\pi/2)}{kr} = \frac{\left[\exp^{-i(kr-l\pi/2)} - \exp^{i(kr-l\pi/2\pi}\right]}{2kr} \tag{2.11}$$

In terms of the reduced wave length:

$$\sigma = \sum_{l=0}^{[2\pi R/\lambda]} (2l+1)\frac{\lambda^2}{4\pi} = \pi(R + \frac{\lambda^2}{4\pi^2})^2 \tag{2.12}$$

Where R is the nuclear radius and $\lambda$ is factors in to the computation of the cross section as effective size of the projectile. When combine equation 2.10 with equation 2.11 gives,

$$\psi_{inc} = A\exp^{ikz} = \frac{A}{2kr}\sum_{l=0}^{\infty} i^{l+1}(2l+1)jl(kr)\Big[\exp^{-i(kr-l\pi/2)} - \exp^{i(kr-l\pi/2\pi}\Big]P_l(\cos\theta) \tag{2.13}$$

The part $\exp^{-ikr}/(kr)$ represents a spherical wave converging on the nucleus, while the $\exp^{ikr}/(kr)$ part represents a spherical wave moving away from the nucleus [5]. The nucleus can only modify the outgoing part. One way of representing this is via a modification of the outgoing part. Thus, the total solution, with incoming and scattered part, is written:

$$\psi_{=}A\exp^{ikz} = \frac{A}{2kr}\sum_{l=0}^{\infty} i^{l+1}(2l+1)jl(kr)\Big[\exp^{-i(kr-l\pi/2)} - \eta_l\exp^{i(kr-l\pi/2\pi}\Big]P_l(\cos\theta) \tag{2.14}$$

Where$\eta_l$ is a complex coefficient that represents the mixing the two parts of the outgoing wave, part of which is associated with the initial plane wave, as well as the scattered part. Thus, the total wave is a combination of both.

$$\psi = \psi_{inc} + \psi_{sc} \tag{2.15}$$

Allowing us to express the scattered part by itself,

$$\psi_{=}\frac{Ai\exp^{ikz}}{2kr}\sum_{l=0}^{\infty}(2l+1)(1-\eta_l)P_l l(\cos\theta) \tag{2.16}$$

As in one dimension we use the probability current density to evaluate the effectiveness of the scattered. The scattered probability current is:

$$j_{sc} = \frac{\hbar}{2im}\left[\psi^*_{sc}(\frac{\partial\psi_{sc}}{\partial r}) - (\frac{\partial\psi^*_{sc}}{\partial r}\psi_{sc})\right] \tag{2.17}$$

Putting equation 2.16 into equation 2.17 results in:

$$j_{sc} = |A|^2(\frac{\hbar}{4kr^2})\left|\left[\sum_{l=0}^{\infty}(2l+1)(1-\eta_l)P_l(\cos\theta)\right]\right|^2 \tag{2.18}$$

Since the incoming wave has probability current

$$j_{inc} = \frac{\hbar k}{m} \tag{2.19}$$

The differential cross section is expressed as following:

$$\frac{d\sigma}{d\Omega} = \frac{j_{sc}}{j_{inc}}r^2 \tag{2.20}$$

In analogy with the 1D transmission and reflection coefficients. Then we can show that

$$\frac{d\sigma_{sc}}{d\Omega} = (\frac{1}{4r^2})\left|\left[\sum_{l=0}^{\infty}(2l+1)(1-\eta_l)P_l(\cos\theta)\right]\right|^2 \tag{2.21}$$

and

$$\sigma_{sc} = \frac{\pi}{k^2}\sum_{l=0}^{\infty}(2l+1)|1-\eta_l|^2 \tag{2.22}$$

Since both the incident and outgoing waves have wave number k, the cross sections discussed above model "elastic" scattering. Elastic scattering characterized by no loss of probability of the incoming particle. Mathematically, this expressed by,

$$|\eta_l| = 1 \tag{2.23}$$

For all *l*. Thus, the only thing that the target does is to redirect the wave and shift its phase.Hence we, define a phase shift, $\sigma_l$, for each $l$-component, using the following convention,

$$\eta_l = \exp^{2i\sigma i} \tag{2.24}$$

From which we can derive

$$\sigma_{sc}^{elas} = \lambda^2 \sum_{l=0}^{\infty} (2l+1) \sin^2 \sigma l \tag{2.25}$$

From now on, we will reserve the name,$\sigma_{sc}$ for elastic scattering only. where $\frac{1}{k} = \frac{\lambda}{2\pi}$

### 2.6.2 Reaction cross section

Generally, however,$|\eta_l| < 1$, as the incoming beam can be absorbed , and part of it unabsorbed. We will identify:

$$\frac{d\sigma_r}{d\Omega} = \frac{j_{in} - j_{out}}{j_{inc}} r^2 \tag{2.26}$$

As the reaction cross section , involving the difference between the current of the incoming and outgoing spherical waves. We see that:

$$\psi_{inc} = \frac{A}{2kr} \sum_{l=0}^{\infty} i^{2l+1}(2l+1) \left[ \exp^{-i(kr - l\pi/2)} \right] P_l(\cos\theta) \tag{2.27}$$

$$\psi_{inc} = \frac{Ai \exp^{-ikz}}{2kr} \sum_{l=0}^{\infty} i2l(2l+1) P_l(\cos\theta) \tag{2.28}$$

$$\psi_{out} = \frac{-A}{2kr} \sum_{l=0}^{\infty} i2l(2l+1) \left[ \exp^{i(kr - l\pi/2)} \right] P_l(\cos\theta) \tag{2.29}$$

$$\psi_{inc} = \frac{-Ai\exp^{-ikz}}{2kr}\sum_{l=0}^{\infty}(2l+1)P_l(\cos\theta) \tag{2.30}$$

Adapting equation 2.17 we obtain the incoming and outgoing probability currents:

$$j_{in} = |A|^2(\frac{\hbar}{4kr^2})\left|\left[\sum_{l=0}^{\infty} i^{2l}(2l+1)Pl(\cos\theta)\right]\right|^2 \tag{2.31}$$

$$j_{out} = |A|^2(\frac{\hbar}{4kr^2})\left|\left[\sum_{l=0}^{\infty}(2l+1)\eta Pl(\cos\theta)\right]\right|^2 \tag{2.32}$$

Combining equation 2.26 with 2.19, 2.31 and 2.32, and then integrating over angles, results in:

$$\sigma_r = \frac{\lambda^2}{4\pi}\sum_{l=0}^{\infty}(2l+1)(1-|\eta_l|^2) \tag{2.33}$$

For elastic scattering,$\sigma_r$

**Total Cross Section**

The total cross section is the sum of the elastic and reaction cross sections. Adding equation 2.22 and 2.33 result in

$$\sigma_t = \sigma_{sc} + \sigma_r = \frac{\lambda^2}{2\pi}\sum_{l=0}^{\infty}(2l+1)[1-\Re(\eta_l)] \tag{2.34}$$

Where $\Re$is some type setting software's idea of "real part "

# 3

# Materials and Method

## 3.1 Materials

The following list of materials have been used to accomplished this research:

- Laptop computer
- Flash disk
- Stationary material
- Computational computer code
- Different plotting software
- Literatures ( books , journals , etc)
- Internet connection.

## 3.2 Methodology

### 3.2.1 Method of Data Collection

For the purpose of performed theoretical calculation of cross section on charge transfer reaction different data has been collected from literature (experimental cross sections of the reaction on selected energies) has been made. After the experimental data of cross section on practical energy is obtained, theoretical calculation of cross section for the reactions at the same energy as the experiment has been made. The calculation has been based on exciton model using ALICE-91 computer program. Where the output of the calculation is not nearer to the experiment, theoretical calculation has been repeated till a good agreement between the calculated and experiment is achieved by changing the value of some input parameters. This involves shifting of input parameters numerically.

### 3.2.2 Method of Data Presentation and Analysis

Both experimental and theoretically obtained data has been displayed in tables. For each mass region reaction the graph of experimental and theoretical data has been plotted. Under each of the tables and graphs discussion has been followed. Based on the discussions conclusion has been given.

# 4

# Results and Discussions

## 4.1 Result

In this section the results of total cross-section for proton induced reaction and neutron induced reaction on the selected target nuclei in different nuclear mass region has been obtained and discussed. The values of the experimental and calculated data has been given in the same table and the graph has been plotted following the tables. In this study on charge transferring reaction the projectile energy up to 18.15MeV has been used as part of input to investigate excitation function. The calculation was done by taking the projectile energy, initial exciton number $n_o = 3$ with configuration (2p+1h+0), the level density parameter(PLD)and the other parameters which are constant. The symbol infront of each parameter is according to the computer program. All parameter has been discussed under each reaction.

| No | Energy of proton(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 6.3 | 76.4 | 70.8 |
| 2 | 7.06 | 89.6 | 103.8 |
| 3 | 8.31 | 100 | 123.9 |
| 4 | 10.75 | 106 | 147.5 |

Table 4.1: The cross section of the experimental and Calculated value of $^{23}_{11}Na(p,n)^{23}_{12}Mg$

### 4.1.1 Excitation Function of Charge Transfer Reaction in Light Nuclear Mass Region

The stable isotope of sodium $^{23}_{11}Na$ has been selected in this nuclear mass region $^{1}_{1}p +^{23}_{11} Na \rightarrow^{23}_{12} Mg +^{1}_{0} n$. The reaction was the proton induce reaction on the target $^{23}_{11}Na$ and during these reaction a single proton charge is transferred from proton to the target $^{23}_{11}Na$ to form $^{23}_{12}Mg$. These made to be the charge has been exchanged in the reaction. The proton projectile energy selected for light nuclear mass region was 6.3-10.75MeV. From this reaction the input parameters were: exciton number $n_o = 5(4p + 1h + 0)$, the level density parameter(PLD)=0. The result of the Cross section for $^{23}_{11}Na(p,n)^{23}_{12}Mg$ reaction was as displayed in Table 4.1.

The table Shows that, the reaction cross section of(p,n)reaction values starts at minimum energy of the projectile about 6.3MeV with 70.8mb and reaches its maximum peak at energy about 10.75MeV with 147.5mb. In the same way the experimental results shows that the reaction cross section value starts at about mini-

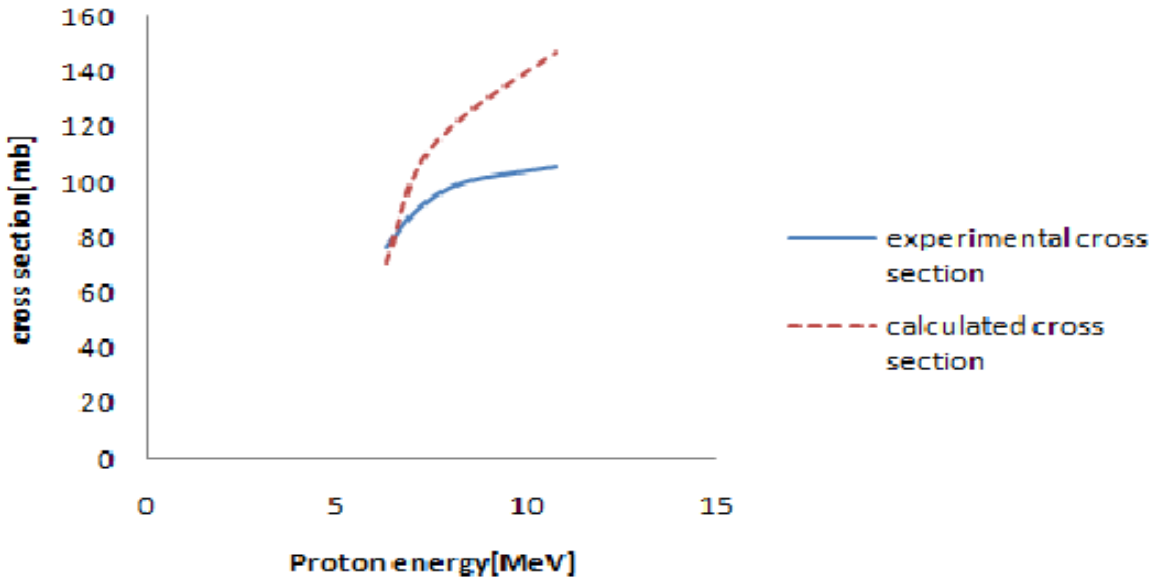


Figure 4.1: Excitation function for ${}^{23}_{11}Na(p,n){}^{23}_{12}Mg$ reaction.

mum energy of the projectile and reaches its maximum peak. Comparatively the experimental and calculated cross section data for the reaction, the excitation functions have been correlated, give better fit and have similar features at the lower and higher energies. The experimental data taken from ref.[26] was done in California Institute of Technology, Pasadena, CA, United States of America. It has been used the statistical model calculation to determine ${}^{23}_{12}Mg + n$ reaction rates in the temperature range $0.5 - 5 \times 10^9$K in the laboratory, but we have been used the exciton model and in both the experimental and calculated the cross section for ${}^{23}_{11}Na + p$ reaction channels were measured over the narrower energy interval[6.3-10.75MeV]. The excitation functions for the reaction is shown in the Figure 4.1. The broken line represents calculated value. The solid line represent experimental data as given in [26]. Figure 4.1. shows that, the relation between cross section and proton energy for charge transfer reaction in light nuclear mass region. The percentage error on

most of these energies was in between $10$ and $20$ percent. This was the best acceptable error since the experimental value expected to have $10$ percent error and theoretically calculated value have $10$ percent error; the $20$ percent error together was acceptable percentage error.

In general, there exists an agreement between the calculated and experimental data, in regard to the minimum and maximum points. Related to the specific values of the reaction, there is a greater gap between the experimental and calculated data as going higher in energy.

The second reaction in light nuclear mass region was the neutron induce reaction on the sodium target.The reaction was given as ${}^{1}_{0}n + {}^{23}_{11}Na \rightarrow {}^{23}_{10}Ne + {}^{1}_{1}p$. During these reaction a single charge was added on to one of the neutron to become residual nucleus being ${}^{23}_{10}Ne$ and an outgoing proton particle. These made to be the charge has been exchanged between the projectile and target in the reaction. The neutron projectile energy has been selected for this reaction 6.3-10.7MeV which is the same as the proton induced projectile energy in Table 4.1. From this reaction the input parameters were: exciton number $n_o = 3(17p + 3h + 0)$, the level density parameter(PLD)=0. The output data of the calculation was as displayed in Table 4.2.

The data in Table 4.2 indicate the reaction cross section of(n,p)reaction values starts at minimum energy of the projectile about 6.3MeV with 51.63mb and reaches its maximum peak at energy about 10.7MeV with 87.5mb.The reaction cross section begin with the maximum and falls down for some interval of energies and finally increased. In the same way the experimental results shows that the reaction cross section value starts at about minimum energy of the projectile and reaches

| No | Energy of neutron(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 6.3 | 32.31 | 51.63 |
| 2 | 7.06 | 29.44 | 40.86 |
| 3 | 8.31 | 47.96 | 47.35 |
| 4 | 10.7 | 93.4 | 87.5 |

Table 4.2: The cross section of the experimental and Calculated value of $^{23}_{11}Na(n,p)^{23}_{10}Ne$.

its maximum peak. Comparatively the experimental and calculated in (n,p)nuclear reaction excitation function relate,give better fit with the experimental value. The experimental laboratory was done in Los Almos National laboratory WNR facility in Belgium. High resolution measurement of neutron induced charged particle reaction on $^{23}_{11}Na$ have been performed. A NaI(TI)detector served as both target and detector, with pulse shape discrimination being applied for the separation of proton from each other [27]. The cross sections of for$^{23}_{11}Na(n,p)$ have been determine in the neutron energy range between 6.3-10.7MeV . All observed cross section show strong fluactions in most of the energy intervals in compling,especially on 6.3and 10.7MeV energies. In the range between 7.06 and 8.31MeV neutron energy,a significant correlation is found between experimental cross section and calculated cross section.

Figure 4.2.The broken line represents calculated value. The solid line represent experimental data as given in [27]. show that, the relation between cross section and neutron energy for charge transfer reaction in lighter nuclear mass region . Related

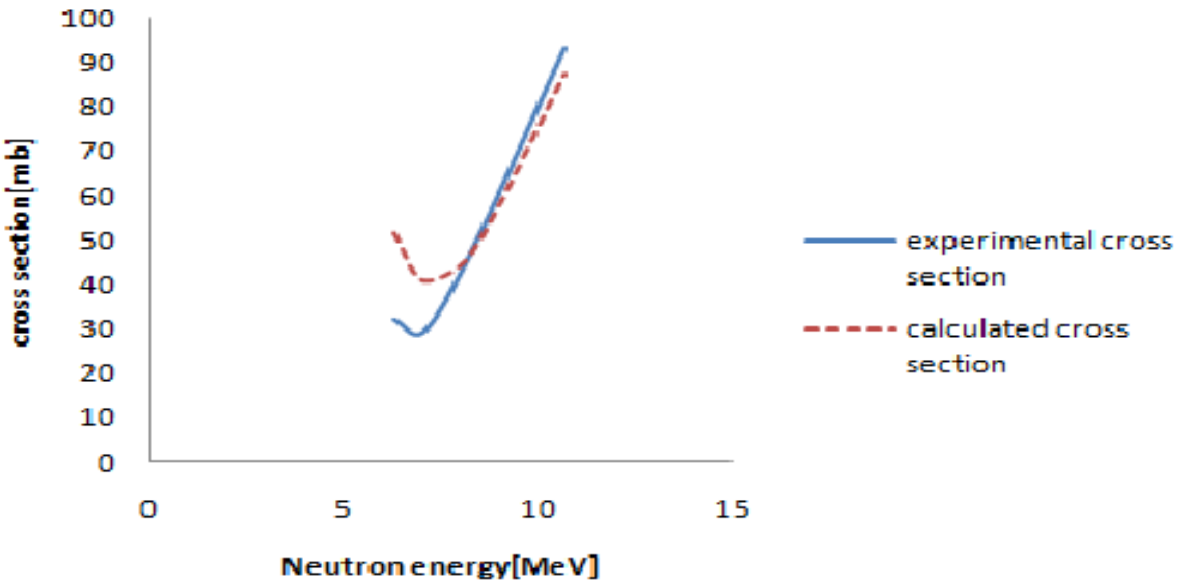


Figure 4.2: Excitation function for ${}^{23}_{11}Na(n,p){}^{23}_{10}Ne$ reaction.

to the specific values of the reaction, there is a some gap between the experimental and calculated data at the beginning than at the end in energy. The percentage error on most of these energies was in between $1.2$ and $20$ percent. These indicate the calculated value was in good agreement with experimental value.

### 4.1.2 Excitation Function of Charge Transfer Reaction in Medium Nuclear Mass Region

The stable isotope ${}^{59}_{27}Co$ cobalt has been selected in this nuclear mass region.

The reaction was given as ${}^{1}_{1}p+{}^{59}_{27}Co \rightarrow {}^{59}_{28}Ni+{}^{1}_{0}n$. The reaction was the proton induce reaction on the target nucleus ${}^{59}_{27}Co$. During these reaction a single charge is transferred from proton to ${}^{59}_{27}Co$ and form ${}^{59}_{28}Ni$ and neutron ${}^{1}_{0}n$ has been emitted. These made to be the charge has been exchange between the reaction. The proton projectile energy selected for medium nuclear mass region was 8-13.8MeV. From this

| No | Energy of proton(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 8 | 511 | 568.7 |
| 2 | 9.4 | 561 | 621.3 |
| 3 | 10.4 | 629 | 655 |
| 4 | 13.8 | 500 | 300 |

Table 4.3: The cross section of the experimental and Calculated value of ${}^{59}_{27}Co(p,n){}^{59}_{28}Ni$.

reaction the input parameters were: exciton number $n_o = 3(1p + 1h + 0)$, the level density parameter(PLD)=10. The output data of the calculation was as displayed in Table 4.3.

The table shows that, the reaction cross section of(p,n)reaction values starts at minimum energy of the projectile about 8MeV with 568.7mb and reaches its maximum peak at energy about 10.4MeV with 655mb and then falls down to minimum cross section 300mb at the projectile energy about 13.8MeV. In the same manner the experimental results shows that the reaction cross section value starts at about minimum energy of the projectile and reaches its maximum peak.Comparatively the experimental and calculated in (p,n)nuclear reaction excitation function related. In the experimental of ref.[28]has been done in Lawrence Livermore National Labratory,Livermore,CA,United States of America.The gadolinium loaded,liquid scintillator detector,and the two competing processes were separated by a statistical analysis.Thick target total neutron yield cross sections were measured. Related to the specific values of the reaction, there is some gap between the experimental and

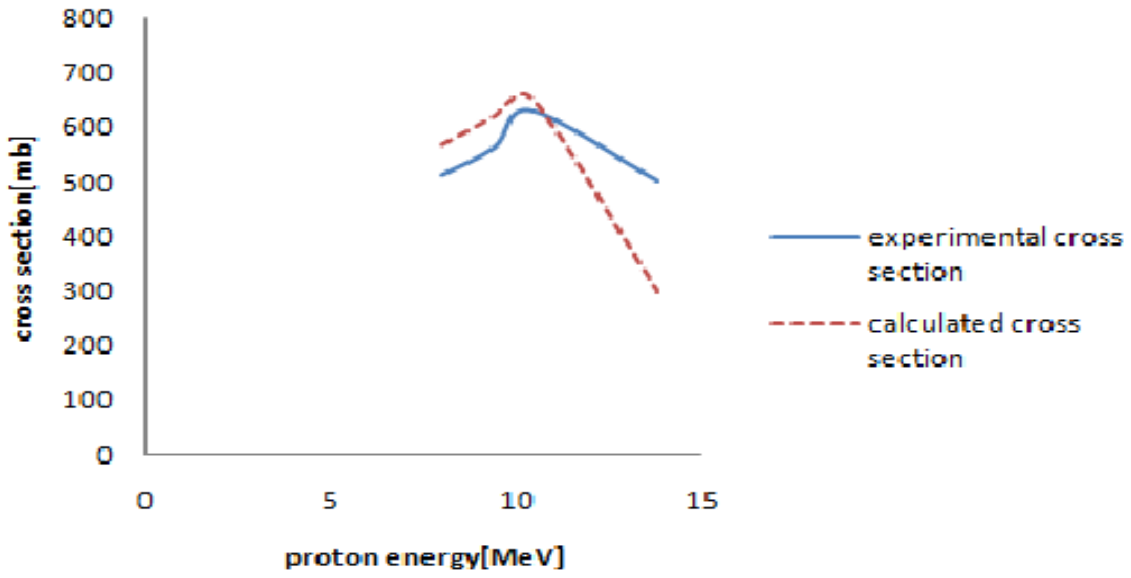


Figure 4.3: Excitation function for ${}^{59}_{27}Co(p,n){}^{59}_{28}Ni$ reaction.

calculated data at the end than at the beginning in energy. The percentage error on most of these energies was in between $4$ and $11.2$ percent.Most of the calculated value was in a good agreement with experimental value, except for the energy 13.8MeV smaller than the experimental value. These is happen because have large range from 10.4-13.8MeV than the other range and other parameters.

Figure 4.3.The broken line represents calculated value. The solid line represent experimental data as given in [28]. Show that, the relation between cross section and proton energy for charge transfer reaction in medium nuclear mass region.

The second reaction in medium nuclear mass region was the neutron induce reaction on the cobalt target. The reaction was given as ${}^{1}_{0}n + {}^{59}_{27}Co \rightarrow {}^{56}_{26}Fe + {}^{1}_{1}p$. In these reaction the charge was taken from target${}^{59}_{27}Co$ to form ${}^{56}_{26}Fe$ and proton${}^{1}_{1}p$ was emitted . The single charge has been exchanged between the reaction. The neutron projectile energy has been selected for this reaction 8.09-13.83MeV which was

| No | Energy of neutron(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 8.09 | 28.9 | 24.68 |
| 2 | 9.43 | 35.7 | 36.13 |
| 3 | 10.41 | 44.8 | 43.77 |
| 4 | 13.83 | 51.2 | 68.74 |

Table 4.4: The cross section of the experimental and Calculated value of ${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$.

approximately the same as the proton induced projectile energy. For the reaction ${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$ the input parameters were: exciton number$n_o = 3(4p + 1h + 0)$,the level density parameter(PLD)=10. The output data of the calculation was as displayed in Table 4.4. The table shows that, the reaction cross section of(n,p)reaction values starts at minimum energy of the projectile about 8.09MeV with 24.68mb and reaches its maximum peak at energy about 13.83MeV with 68.74mb. In the same way the experimental results shows that the reaction cross section value starts at about minimum energy of the projectile and reaches its maximum peak. Comparatively the experimental and calculated in (n,p)nuclear reaction excitation function relate, give better fit and have similar features at the lower and higher energies. In this case almost all the calculated values are related with the experimental values. The experiment in ref.[29] was done in Physikal. Techn. Bundesanst.Braunschweig, Germany. In each irradiation was accompanied by a separate measurement with an empty gas cell to compensate for low-energy neutrons generated in the materials of the target (GAS-OUT). Scintillation detector used for neutron registration.

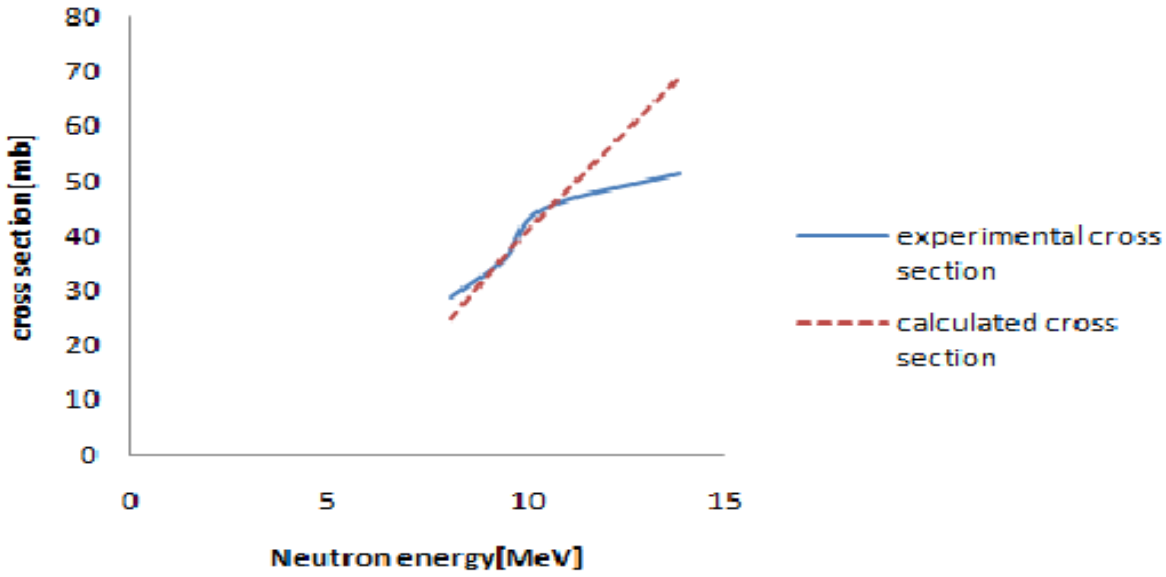


Figure 4.4: Excitation function for ${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$ reaction.

Figure 4.4.The broken line represents calculated value. The solid line represent experimental data as given in [29]. Figure 4.4 shows that, the relation between cross section and neutron energy for charge transfer reaction in medium nuclear mass region. Related to the specific values of the reaction, there is some gap between the experimental and calculated data at the end than at the start in energy. The percentage error on most of these energies was in between $1.2$ and $2.2$ percent. The calculated was in agreement with experimental value measured.

### 4.1.3 Excitation Function of Charge Transfer Reaction in Heavy Nuclear Mass Region

The stable isotope ${}^{197}_{79}Au$ gold has been selected in this nuclear mass region.

The reaction was given as ${}^{1}_{1}p + {}^{197}_{79}Au \rightarrow {}^{197}_{80}Hg + {}^{1}_{0}n$. The reaction was the proton induce reaction on the target nucleus ${}^{197}_{79}Au$and ${}^{197}_{80}Hg + {}^{1}_{0}n$ has been formed.

| No | Energy of proton(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 13.3 | 41 | 39.17 |
| 2 | 14.17 | 41.18 | 39.71 |
| 3 | 15 | 113 | 100 |
| 4 | 18.15 | 28.69 | 40.42 |

Table 4.5: The cross section of the experimental and Calculated value of ${}^{197}_{79}Au(p,n){}^{197}_{80}Hg$.

During these reaction the single charge was given to target ${}^{197}_{79}Au$ from proton and form ${}^{197}_{80}Hg$ and neutron ${}^{1}_{0}n$ has been emitted these made to be the charge has been exchange in the reaction. The proton projectile energy selected for heavy nuclear mass region was 13.3-18.15MeV. From this reaction the parameters compiled are: exciton number$n_o = 4(4p + 1h + 0)$, the level density parameter(PLD)=10. The output data of the calculation was as displayed in Table 4.5.

The table shows that, the reaction cross section of(p,n)reaction values starts at minimum energy of the projectile about 13.3MeV with 39.17mb and reaches its maximum peak at energy about 15MeV with 100mb and then falls down to minimum cross section 40.42mb at the projectile energy about 18.15MeV. In the same manner the experimental results shows that the reaction cross section value starts at about minimum energy of the projectile and reaches its maximum peak.Comparatively the experimental and calculated in (p,n)nuclear reaction excitation function relate,give better fit.The experiment in ref.[30,31,32]was done in Lawrence Livermore National Laboratory, Livermore, CA, United States of America. The percentage error

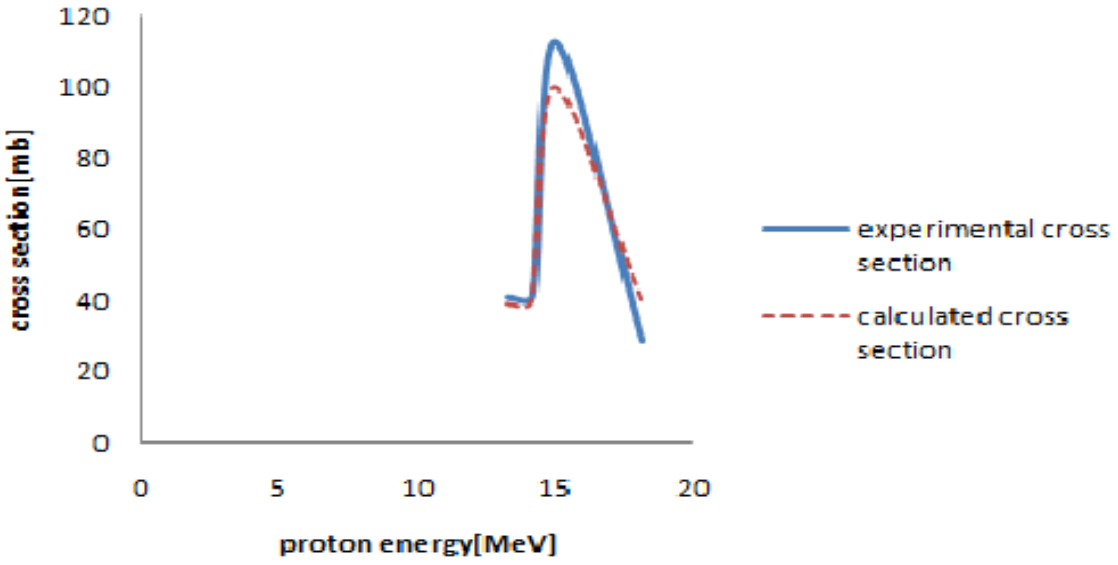


Figure 4.5: Excitation function for $^{197}_{79}Au(p,n)^{197}_{80}Hg$ reaction.

on most of these energies was in between $3.5$ and $11.5$ percent. This was the best acceptable error since the experimental value expected to have $10$ percent error and theoretically calculated value have $10$ percent error; the $20$ percent error together was acceptable percentage error. In general, there exists an agreement between the calculated and experimental data, in regard to the minimum and maximum points. Related to the specific values of the reaction, there is a greater gap between the experimental and calculated data on higher energy.

Figure 4.5. The broken line represents calculated value. The solid line represent experimental data as given in [30,31,32]. Figure 4.5 shows that, the relation between cross section and proton energy for charge transfer reaction in heavy nuclear mass region. Most of the calculated values are in good agreement with the experimental value measured on the EXFOR libraries by [30,31,32], except of the energy value 18.15MeV. These is because of the energy the experimental value is not available on

| No | Energy of neutron(MeV) | $\sigma$ Experimental value(mb) | $\sigma$ Calculated value(mb) |
|---|---|---|---|
| 1 | 13.4 | 1.4 | 1.59 |
| 2 | 14.09 | 2 | 2.37 |
| 3 | 14.93 | 2.6 | 3.57 |
| 4 | 17.95 | 6 | 10.44 |

Table 4.6: The cross section of the experimental and Calculated value of $^{197}_{79}Au(n,p)^{197}_{78}Pt$.

the same reference and taken from different year of the EXFOR libraries than the other energies, so that the value is becomes to be maximum at this energy.

The second reaction in heavy nuclear mass region was the neutron induce reaction on the gold target. The reaction was given as $^{1}_{0}n +^{197}_{79} Au \rightarrow^{197}_{78} Pt +^{1}_{1} p$. During these reaction the single charge was taken from target$^{197}_{79}Au$ and form $^{197}_{78}Pt$ proton $^{1}_{1}p$ has been emitted . These was the over all behavior about this reaction made to be the charge has been exchanged between the projectile and the target. The neutron projectile energy has been selected for this reaction 13.4-17.95MeV which was approximately the same as the proton induced projectile energy. From the reaction the input parameters were: exciton number $n_o = 4(3p+1h+0)$, the level density parameter(PLD)=0. The output data of the calculation was as displayed in Table 4.6. The table shows that, the reaction cross section of(n,p)reaction values starts at minimum energy of the projectile about 13.4MeV with 1.59mb and reaches its maximum peak at energy about 17.95MeV with 10.44mb. In the same way the experimental results shows that the reaction cross section value starts at about minimum energy of

the projectile and reaches its maximum peak. Comparatively the experimental and calculated in(n,p)nuclear reaction excitation function resemble, give better fit and have similar features at the lower and higher energies. The experimental in ref.[33] was done in the laboratory of Los Alamos Cockeroft Walton. Gas target at the large Van de Graaff acceletor has been used. The products were isolated and measured by radiochemical methods. The procedures used for the chemical separations are described. Empirical formulae are given for estimating (n,p)cross section at maximum and at 14MeV, but we have been used exciton model computer code. These data of calculated value is much related to the experimental. Related to the specific values of the reaction, there is a greater gap between the experimental and calculated data as going higher in energy. The percentage error on most of these energies was in between $10$ and $20$ percent. Almost all are in a good agreement. Values of calculated is greater than the experimental value. While experimental was maximum the calculated value also maximum in these reaction.

Figure 4.6. The broken line represents calculated value. The solid line represent experimental data as given in [33]. Show that, the relation between cross section and neutron energy charge transfer reaction in heavy nuclear mass region. The best acceptable error was obtained, since the experimental value expected to have $10$ percent error and theoretically calculated value have $10$ percent error; the $20$ percent error together was acceptable percentage error.

In general, there exists an agreement between the calculated and experimental data, in regard to the minimum and maximum points. Related to the specific values of the reaction, there is a greater gap between the experimental and calculated data

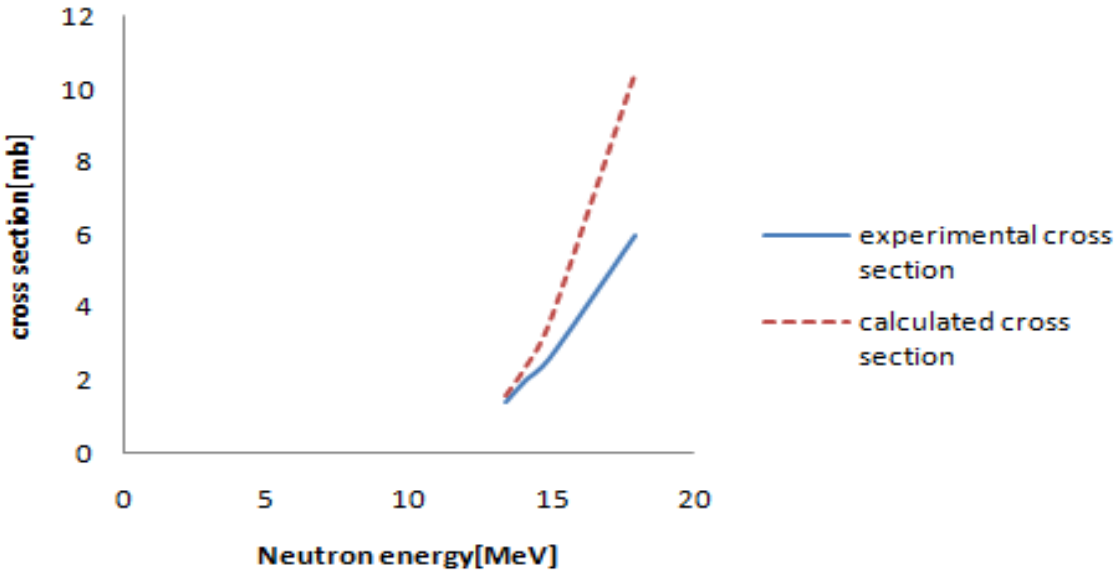


Figure 4.6: Excitation function for $^{197}_{79}Au(n,p)^{197}_{78}Pt$ reaction.

as going higher in energy.

# 5

# Conclusion

From the above result the excitation functions of ${}^{23}_{11}Na(p,n){}^{23}_{12}Mg$,${}^{23}_{11}Na(n,p){}^{23}_{10}Ne$,${}^{59}_{27}Co(p,n){}^{59}_{28}Ni$, ${}^{59}_{27}Co(n,p){}^{56}_{26}Fe$,${}^{197}_{79}Au(p,n){}^{197}_{80}Hg$ and ${}^{197}_{79}Au(n,p){}^{197}_{78}Pt$ reaction over proton and neutron energy ranging from 6.3MeV to 18.15MeV in different nuclear mass region was analyzed. The calculation have been carried out using nuclear exciton model. It is concluded that by adjusting the value of input parameters and by choosing the appropriate level density parameter as well as the exciton number one can predict (p,n ) and (n,p ) reaction cross sections for different nuclear mass region from 6.3MeV to 18.15MeV closer to the available experimental data. The percentage error on most of energies in light nuclear mass region reaction was in between $1.2$ and $15.8$ percent,in medium nuclear mass region reaction was in between $1.2$ and $11.2$ percent and in heavy nuclear mass region reaction was in between $3.5$ and $15.6$ percent. This was the best acceptable error since the experimental value expected to have $10$ percent error and theoretically calculated value have $10$ percent error; the $20$ percent error together was best acceptable percentage error. Comparatively the experimental and calculated cross section data for the reaction, the excitation functions have been in a good agrement, correlated, give better fit and have similar features over

all energies. Furthermore, the reaction cross section as the proton projectile energies were maximum in the light nuclear mass region maximum, in medium nuclear mass region maximum for the lower energies and minimum for the higher energies and in heavy nuclear mass region minimum, while in the neutron projectile energies was increased in light nuclear mass region increased, decreased and increased as energies lower, intermediate and higher respectively. But, in medium and heavy nuclear mass region is increased. Additionally, the effect of the projectile energies on the cross section in different nuclear mass region, which have different characteristics from one nuclear mass region to the other in charge transfer reaction. We have also observed that there is significant contribution of the effect of nuclear mass region in (p,n)and (n,p ) reaction cross section of all charge transfer nuclear reactions.

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