Systematic behavior of the fusion barrier parameters for heavy ion pairs

By

Abdulghany Reda Abdulghany Ahmed

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Systematic behavior of the fusion barrier parameters for heavy ion pairs

Name of candidate

Abdulghany Reda Abdulghany Ahmed

This thesis has been approved for submission by the supervisors:

1- **Prof. Dr. Mahmoud Yahia Ismail**
Physics Department - Faculty of Science - Cairo University

Signature:

2- **Dr. Ali Yahia Ellithi**
Physics Department - Faculty of Science- Cairo University

Signature:

Prof. Dr. Gamal Abd-Elnaser Madbouly
Chairman of Physics Department
Faculty of Science - Cairo University

Signature:

ABSTRACT

The nucleus-nucleus potential is calculated in the frame work of the double folding model (DFM) to obtain the Coulomb barrier parameters (barrier position and height), starting from M3Y-Reid nucleon-nucleon interaction and realistic nuclear matter distribution. The systematic behavior of the barrier parameters with mass numbers, charges, and radii of interacting nuclei is studied. The relation between the barrier height and radius is also discussed. The systematic behavior of the barrier parameters is presented in the form of simple analytical formulae, which can be used to calculate the barrier position and height directly, and show which factors can affect them.

The potentials obtained from DFM are used to derive a universal function of the nuclear proximity potential which is useful for barrier calculations for heavy ion reactions. The obtained universal function reproduces the barrier parameters within less than 2% deviation from the values obtained using DFM for heavy and super heavy ion reactions. Reactions involving α-particle are studied individually, and another form of the universal function is presented.

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Preface

In the last few decades, the study of nuclear reactions became one of the most interesting fields of physics. The main focus was on production of energy; however, nuclear studies affect many vital fields, such like medicine, biology, archeology and militarism. As the building of accelerators developed the scientific ambition developed, and many studies were performed on the synthesis of new super heavy elements (SHE). This opened up a new field of research termed as heavy-ion collision physics. Most of our information is obtained from studies made on stable nuclei for the simple reason that they are far easier to handle in the laboratory. This is a very special group among all the possible ones that can be formed. Synthesis of SHE is a great challenging topic, not to get the SHE itself, but to get a detailed picture about the shell stabilization and structure effects. This also gives a new tool to test the nuclear theories, or even develop them.

The building blocks of nuclei are neutrons and protons, two quantum states of the same particle, the nucleon. Both gravitational and electromagnetic forces are infinite in range and their interaction strengths diminish with the square of the distance of separation. Clearly, nuclear force cannot follow the same radial dependence. The nuclear force has a very short range, not much beyond the confine of the nucleus itself. In 1935, Yukawa proposed that the force between nucleons arises from meson exchange. This was the start of the concept of field quantum as the mediator of fundamental forces. The reason that nuclear force has a finite range comes from the nonzero rest mass of the mesons exchanged. For the nucleons inside a nucleus, nuclear force is far stronger than that due to electromagnetic interaction. This force keeps the protons and the neutrons bound to the nucleus, and it makes the nuclear reactions possible.

The interaction between two nuclei is governed by the repulsive Coulomb potential and the attractive nuclear potential, which in combination form the potential barrier; this barrier has to be penetrated for fusion to occur. Understanding the physics of fusion of heavy ions is still a central topic of research in nuclear physics. For this purpose many studies of fusion barrier have been done. Well knowledge of fusion barrier parameters (barrier height and barrier position) gives a great idea about the process of fusion and tells us about the conditions needed to get the wanted result. In chapter (1) of the present thesis we review the effect of different factors such like, masses, charges, diffuseness of nuclear matter, and radii of the interacting pair on the barrier parameters. We introduce the behavior of the fusion barrier parameters in the form of simple analytical formulae, not only to get a simple method to predict the values of barrier parameters, but also to show which factors can affect them. In chapter (2) we introduce a method to calculate nuclear potential around the barrier position. We use the advantages of two different models, the first is the “double folding model” which characterized by its great validity in the tail region (around the barrier position), and the second is the “proximity model” which characterized by the accessibility in the calculation of nuclear interaction. We used the results of detailed calculations through the double folding model to introduce a new shape of the universal function useful in barrier calculations for heavy ion reactions. We also study the reactions involve α-particle individually,

because of its odd characteristics, and we introduce a universal function useful for reactions involve α-particle and α-decay.

Chapter 1

Systematic behavior of the fusion barrier parameters using the double folding model

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1.1 Introduction

The interaction between two nuclei is governed by two potentials, the first is the repulsive Coulomb potential and the second is the attractive nuclear potential. The combination between these potentials forms the potential barrier; this barrier has to be penetrated for fusion to occur. The nucleus-nucleus potential [1- 3] plays an important role in the description of fusion in any model [3-7]. Coulomb interaction is well known from the classical treatment of the electrostatic force between charged bodies, but the nuclear contribution of the interaction potential is less known. For many studies of nucleon and light ion scattering, the major part of the nuclear interaction potential can be approximated by a Woods-Saxon (WS) form [8-11] which gives a simple analytic expression. The WS real potential combined with an imaginary part of the same radial shape, or slightly modified shape, forms the optical model potential [12-16]. This potential has been used successfully for the scattering of light ions.

Historically, the basis of the optical model was developed by comparing the results of the scattering of neutrons by nuclei to those obtained in optics for the scattering of light by transparent spheres. The first optical potentials were built for the interaction of neutrons with nuclei and afterwards for the scattering of protons [17, 18], α- particles [19] and heavy ions [5, 20-22]. The optical potential consists of two parts; the first part is a real part and it deals with the refraction, the second is an imaginary part and it deals with the absorption into reaction channels.

The interaction between heavy ions (HI) may be quite complicated; however, if we are only interested in the averaged properties, it is possible to simplify the situation by a large extent. An optical model potential for interaction between target and projectile can represent the average interaction between the incident nucleons in the projectile nucleus and nucleons in the target nucleus. It, therefore, replaces the complicated many body problem posed by the interaction of two nuclei by the much simpler problem of two particles interacting through a potential. A microscopic model of the potential may be constructed by folding the fundamental nucleon-nucleon interaction with the nuclear