CHAPTER I

INTRODUCTION

I.1. Introduction

Heavy ion collision experiments present a rapidly developing field of research in atomic and nuclear physics. It is now possible to study atomic physics far beyond the region of stable elements. This includes the interesting electrodynamic phenomena associated with an overcritical coulomb field[1-5] that can effectively be obtained when two heavy ions (atoms) come close enough to form, for a short while, a quasi molecule. It has been recognised that a careful study of the positrons emitted from this system should be able to provide useful information regarding the basic problem of the interaction of an electron with a strong coulomb field. Although conventional perturbation techniques are not applicable here, significant progress has nevertheless been achieved in interpreting qualitatively the accumulating data on the over critical field problem. The interpretation of the results is, however, complicated because of the fact that positrons may be produced through a number of mechanisms. Apart from a spontaneous decay of the neutral vacuum[6] there is the possibility of dynamically induced transitions between adiabatic electronic states, leading to positron emission. This may occur also for states that are not overcritical. Positrons produced by these processes, are, however, distinguishable. While the positrons produced in spontaneous vacuum decay should have the energy of the bound state resonance, the energy spectrum in the induced decay should be much broader. Positrons could also be produced as a 'shake-off' of the strong vacuum polarization cloud[7] close to the nuclei. Lastly, positrons could be produced as a result of nuclear processes. Thus, one of the nuclei could be coulomb excited and the high energy photon emitted could be internally converted. It is obvious that a careful study of all these processes should be made before one can confirm the theoretical concepts. The strong time-dependence of the collision process plays an important role in the theoretical formulation of the problem. During the collision, the length of the vector $\vec{R}$ connecting the two nuclei changes in time and $\vec{R}$ also undergoes a rotation. Some relief, however, comes through the fact that the motion of the nuclei can be described to a good accuracy from a semiclassical consideration, and in some cases, simply by Rutherford scattering formula.

Apart from atomic physics, heavy ion experiments have also opened up new fields of study in nuclear physics. The nucleus has now been subjected to much more severe perturbations than were earlier possible with lighter projectiles. New reaction processes have become accessible owing to the availability of higher kinetic energy and angular momentum. Also, the search for exotic phenomena like the production of shock waves and superdense matter with the associated phase transition is continuing. Although the studies of proton and pion spectra and their multiplicities have not yet given any signal for the occurance of these phenomena, the possibilities are not yet ruled out. Some progress has also been made in the study of very neutron rich light nuclei using heavy ion reactions at low energies[8]. The study of nuclear states with high angular momenta has become another subject of interest in heavy ion physics. Also, the possibility of transferring a large number of particles provides a new technique to probe into excited states of nuclei. These deep inelastic transfer phenomena have also been studied within the frame work of statistical mechanics with remarkable success. It is expected that the studies on the entire range of heavy ion reactions, elastic, inelastic, transfer phenomena and fusion will provide us a deep insight into the properties of nuclei and the nature of nuclear force in near future. The heavy ion reactions herald the begining of a new area of physics, which will develop, giving rise to many new concepts as the experimental information and the theoretical interpretation become more precise.

The collision of two ions or atoms is a complicated many body problem and a detailed analysis is called for to extract the relevant information from the heavy ion data. A crucial role is played by the elastic scattering cross-section. Attempts have been made to study various elastic scattering processes assuming different optical model potentials between the colliding nuclei. It is generally hoped, though not confirmed, that a suitable complex optical potential will suffice to describe the elastic scattering results. The interaction potential may be useful also for solving the equation of motion for heavily damped collision, because the driving force is the gradient of the interaction potential. The concept of scattering from a complex potential has, therefore, been subjected to considerable scrutiny in connection with the heavy ion reactions. The data from elastic scattering experiments with a variety of projectiles and targets are now available and some attempts have been made to fit these data with potential models, mostly of the Woods-Saxon type. Although a direct numerical method of computing the phase shifts and hence the cross-section still remain the most dependable way of studying the heavy ion scattering, it has been realised since the early days of heavy ion physics that semiclassical methods may be quite useful in this field. The large value of the Sommerfeld parameter $\eta = \frac{Z_1 Z_2 e^2}{\hbar v}$ and the large value of the reduced mass induce a more classical behaviour than when the projectile is a light particle. Naturally, considerable attention was paid to the study of heavy ion processes in the semiclassical approach. This also helped in model building because one could follow the interacting ions during the whole reaction time.

While the extensive work on the semiclassical methods in connection with the heavy ion scattering brought out many new interesting features, no semiclassical method has so far been found suitable for an accurate calculation for a realistic heavy ion scattering. It appears that further work is needed in this field to exploit fully the versatility of the semiclassical approach.

I.2. Aim of the work

The aim of the present work is to study the accuracy and efficacy of a particular semiclassical method, first suggested by Miller and Good, for application to the study of heavy ion elastic scattering. This we intend to do in steps. The accuracy of the method is first checked by considering some simple real as well as complex potentials. The method is next applied to a typical case, viz. ^{16}O - ^{16}O elastic scattering. The emphasis has been on testing the applicability and thus highlighting the practical difficulties, if any, in working with the semiclassical method, rather than studying the ^{16}O - ^{16}O scattering process very accurately. Thus, we have considered the optical model potential obtained by

Maher et al[9], although it is known that this potential does not fit the experimental data for energies greater than 25 Mev. We have considered a simple generalization of the Miller-Good method suitable for complex trajectories and the extensive work of Knoll and Schaeffer in this field has been very useful in choosing the contributing trajectories when more than one turning points are relevant.

I.3. Summary of the work

The scheme of presentation is as follows:

(a) In Chapter II, we have discussed briefly the Miller-Good semiclassical method and its generalization for complex trajectories, which we intend to apply for the study of some scattering phenomena, including a typical heavy ion elastic scattering process.

(b) In Chapter III, we have applied the Miller-Good method to two types of potentials: (i) real potentials like Ywkawa and Exponential and its complex generalization and (ii) a complex potential of the type $\frac{a}{r} - \frac{i\beta}{r^2}$. The calculated results for the real potentials were compared with exact results and the accuracy of the method for real potentials were checked. The complex potential (ii) is interesting also because the relevant Schrödinger equation is exactly solvable and the exact complex phase shifts can be obtained analytically. The generalized semiclassical method is then applied to this potential. The semiclassical phase shifts have been shown to be fairly accurate over a wide range of values of the parameters, and even at fairly low energies. This encourages one to apply the method to the study of realistic problems, e.g. heavy ion scattering phenomena.

(c) In Chapter IV, we have first considered the effect of the nuclear coulomb field in the ^{16}O - ^{16}O elastic scattering by applying the real Miller-Good method, and treating the absorptive part of the potential perturbatively. In calculating heavy ion scattering cross-section, it has been the usual practice to treat the coulomb effect approximately. Thus the potential taken is obtained either by (a) considering a point charge and a sphere of uniform charge density or (b) that between two uniformly charged spheres. When the nuclei are heavy and have Fermi type of charge distributions, the approximation is a good one. But it is not obvious that the approximation will be valid for light nuclei like (^{12}C, ^{16}O etc.) in the region where the charges overlap. We have, therefore, made semiclassical calculations taking two types of charge distributions: (i) uniform and (ii) modified harmonic well distribution, which is the accepted distribution for p-shell nuclei. It has been seen that the difference of phase shifts in the two cases is noticeable at least for some low L values.

The cross-sections in general do not show much difference. However, it has been pointed out that there is some justification for choosing the realistic charge distribution for light nuclei like ^{12}C, ^{16}O when one tries to fit an entire range of experimental results of heavy ion scattering, like elastic scattering, transfer phenomena, fusion etc.

We have next applied the complex Miller-Good method to study a typical ^{16}O - ^{16}O elastic scattering phenomena at a high energy. The prescription of Knoll and Schaeffer has been followed in the selection of important trajectories. The perturbative method of treating complex potential has also been considered for this problem. The two results have been compared. The difficulties in applying a complex semiclassical method for a quantitative calculation have been pointed out. Our conclusions are also summarized.

I.4. Computational work

We have written down two programs for calculating (i) the phase shifts by the semiclassical Miller-Good method including the first order correction term in $\hbar^2$ for some simple potentials and (ii) a program to calculate the phase shifts and cross-sections for elastic scattering of p-shell nuclei with complex trajectories for cases where there is contribution from only one complex turning point. The charge distribution could be either (i) uniform or (ii) modified harmonic well type. The phase shifts have been calculated explicitly upto L = 100 and for higher L, the phase shifts have been assumed to be given by those of the coulomb field. The cross-section has been symmetrized for identical nuclei and the ratio of the cross-section to Mott scattering cross-section has also been computed.

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