NUCLEAR FUSION PARAMETERS OF HEAVY ION INDUCED REACTIONS

THESIS

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C O N T E N T S

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SUMMARY

A study for fusion mechanism of both light and massive heavy ions is presented. Study of the fusion limiting mechanism (of light-heavy ions) is the first part of the thesis. For massive heavy ions, the very strong enhancement of experimental fusion cross section relative to the current theoretical predictions is the problem studied in the second part of the thesis. The basic results are :

(I) For light heavy ions : ^{20}Ne + ^{40}Ca fusion system :
The diffraction model analysis of $^{20}Ne+^{40}Ca$ elastic scattering data (44.1 MeV $\leqslant E_{lab} \leqslant$ 151 MeV) were performed to determin cut-off orbital angular momentum L_c and total reaction cross-section (σ_r).

A Fermi function type for fusion probability was proposed and used in a partial wave expansion for calculating fusion cross-section (σ_{fus} (E)) for $^{20}Ne+^{40}Ca$. The derived fusion angular momentum (L_f) together with (L_c) accounted for the observed saturation limit of σ_{fus}(E) and resulted in a rough estimate for the associated energy drop (Δ E). Saturation limit is clearly manifested at high energy as pocket in the effective potential disappears and neither energy drop (Δ E) nor reduction in the entrance channel angular momentum (L_c-L_f) can compensate for the repulsive centrifugal potential.

(II) For massive heavy ions : fusion of $^{58,64}Ni$ with $^{58,64}Ni$:

1) The one dimensional barrier penetration model was successfully applied in discription of the excitation function for complete fusion of $^{58}Ni+^{58}Ni$ system particularly at far sub-barrier energies. Using different nuclear potentials (proximity, NGÔ, KNS and SWW potentials) a very strong sensitivity to changes in nuclear radius parameter (r_o) was established for fitting this high precision data.

2) The upper limiting changes required, using any of the above mentioned nuclear potentials, was Δr_o = 0.065 fm.

3) The minor monotonic increase of r_o with decreasing energy was manifested in geometry of the barrier and the attractive nature of the nuclear potentials (involved) in the surface region.

4) Δr_o was correlated to the parameter α which describe deviation from spherical symmetry (i.e. spherodity) of the nuclei involved. This dynamical deformation associated with fusion of these massive nuclei is a neccessary condition for successful description of their fusion mechanism. The same procedure was extended to cover fusion of $^{64}Ni+^{64}Ni$ system.

5) Values of α derived from both $^{58}Ni+^{58}Ni$ and $^{64}Ni+^{64}Ni$ fusion channels were combined and satisfactory predicted experimental results of the $^{58}Ni+^{64}Ni$ fusion channel. This could be considered as, successful justification for the present work. and improvement to the one dimensional fusion barrier model calculations as compared to the recent work of Beckerman et al. (1982).

INTRODUCTION

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In reactions between heavy ions the total reaction cross-section is generally composed of two well separated components. One represents a more or less damped scattering process with approximate preservation of the initial mass asymmetry, whereas the other involves a thorough amalgamation of the two colliding systems usually referred to as fusion. The above mentioned distinct channels through which heavy ions proceed is shown schematically in Fig. (1).

For light systems fusion is a dominant part. In the studies of excitation functions for fusion cross-sections of light heavy ion system, a more or less pronounced bend in the rising slope and often a saturation of the cross-section is observed.

Different approaches were proposed for this limitation of the fusion cross-section ($\sigma_{fus}(E)$). Harar [1] suggested that fusion limiting mechanism could be due to an angular momentum limitation imposed by the properties of the compound nucleus. Kolata [2] attributed this limitation in some way to properties of the compound system and that its onset is more violent than previously suspected. On the other hand deformation and shell effects, included in determining yrast

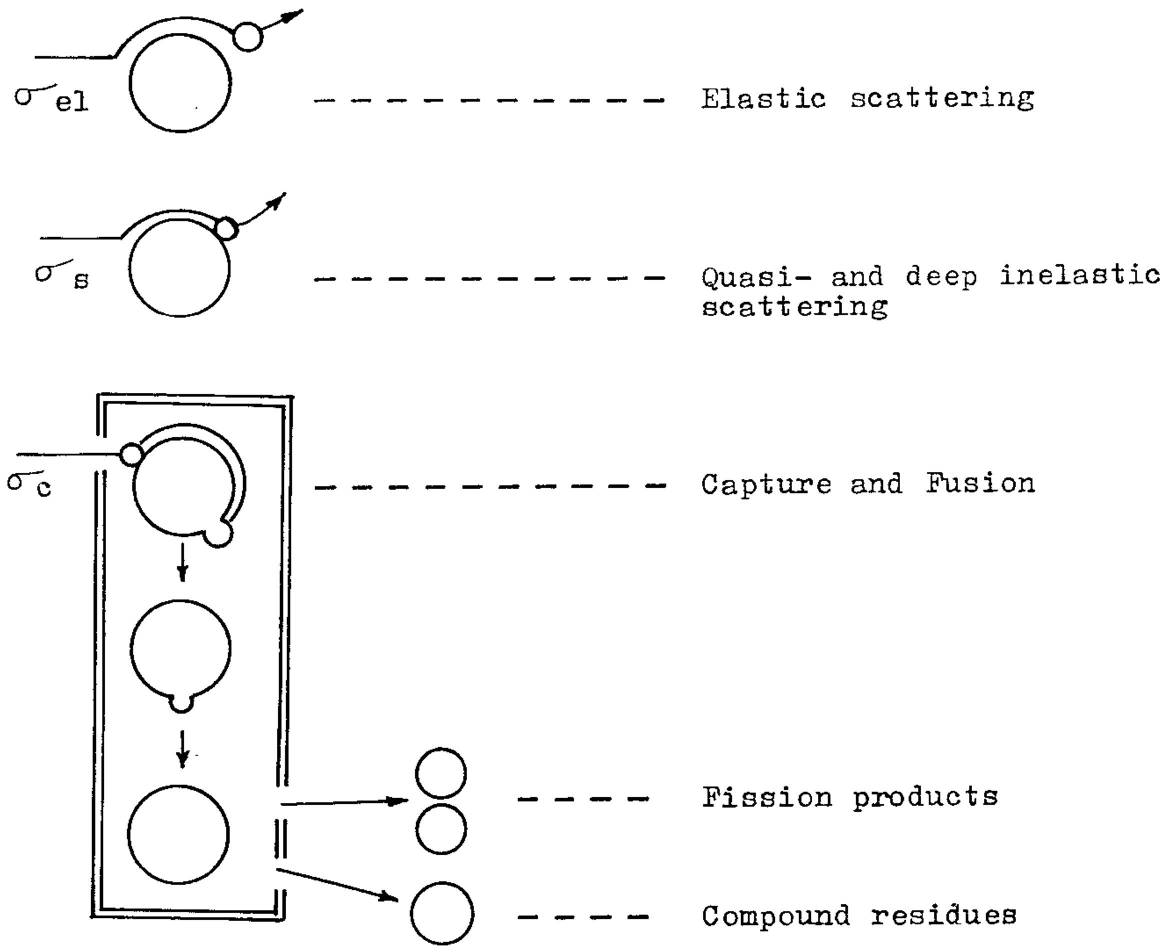

Fig. 1 : Heavy ion reactions tends to proceed through two distinct channels. Either the nuclei scatter from each other, and we observe two products of approximately the same mass as the initial nuclei with angular distribution peaked near the grazing angle. The two nuclei may alternatively fuse together and result in the formation of compound residues or in the appearance of two fission products of approximately equal mass.

line cannot be responsible for the observed drop of σ_{fus} below σ_{react} [3] . In a data for the fusion energy excitation function of the light heavy ion system, $^{20}Ne+^{40}Ca$, over the energy range 40-70 MeV and at 151 MeV a limitation of σ_{fus} (E) was observed at $E_{lab} \leqslant 151$ MeV and represents about half of the corresponding total reaction cross section [4,5]. The first part of the present work is an attempt to attribute this observation to reduction in entrance channel angular momentum, due to tangential friction, by establishing a systematic difference between cut-off L_c and fusion angular momentum (L_f). The $^{20}Ne+^{40}Ca$ data set was chosen as it includes both elastic scattering and fusion cross-sections, to determine L_c and L_f respectively, over a wide range of energies.

For medium heavy ion systems increasing body of high precision data measurements of excitation function for complete fusion of massive nuclei at near and sub-barrier energies are now available (Beckerman et al. [6,7]). These data are fruitful sources in providing insight into the interplay between fusion dynamics and the underlying nuclear structure. A prototype example is the $^{58}Ni+^{58}Ni$ complete fusion data at $187.6 \leqslant E_{lab} \leqslant 220$ MeV. The cross-section for complete fusion at sub-barrier energies are found to be far greater (more than two orders of magnitude) than those pridicted by the standard one-dimensional barrier penetration model (Beckerman et al. [7]). This large sub-barrier fusion cross-sections was tried to be explained within a liquid drop framework as a sequence of zero point motion. Landowne and Nix [8] presented calculations for $^{58}Ni+^{58}Ni$ systems which took into account average dynamic deformations as well as zero-point motion. Their results were an excitation function similar to that for penetration of a one-dimensional barrier by spherical nuclei. The substantially increase in fusion cross-section arising from zero-point motion is however, insufficient to explain the observed large sub-barrier fusion data. A phenomenological analysis based on one-dimensional barrier penetration model, employed the WKB method (in calculating the transmission coefficient) and introduce a radially dependent effective mass has been carried out by (Beckerman et al. [9]). Although a close agreement to $^{58}Ni+^{58}Ni$ fusion data was obtained, still at far sub-barrier energy better fit to data is needed. The extent to which the simple one dimentional barrier (approximated to inverted harmonic oscillator) model can accounted for sub-barrier fusion data and strong sensitivity of the $^{58}Ni+^{58}Ni$ high precision fusion data to type and geometry of nuclear potential involved has been studied by introducing a minor (Δr_o) monotonic increase of nuclear radius parameter r_o, with energy. This study representing the second part of the present thesis. Also included in this part, (i) the correlation between Δr_o and the deformation parameter (α) describing deviation from spherical symmetry of the nuclei involved (ii) and extension to both $^{64}Ni+^{64}Ni$ and $^{58}Ni+^{64}Ni$ fusion channels.

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CHAPTER I

ELASTIC SCATTERING AND FUSION OF HEAVY IONS

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I.1- Elastic Scattering :

The basic task of nuclear reaction theory is to find a solution of the Schrodinger equation of the system under consideration that satisfies the appropriate boundary condition. This Schrodinger equation is many particle one, so that the total wave function depends on the coordinates of all the interacting particles, and the potential is the sum of all the interactions between them. To solve that the interaction between the incident particle and the target nucleus can be represented by a simple one body potential V(r), where r is their separation. The method of calculation will be described first of all for the simplest case, that of spinless neutral particle scattered from a spherical local potential.

I.2- Scattering by a Central of Force Field :

Consider a beam of charged particles which is incident upon a small spherically symmetric region (the potential depends on r only), the particles have a certain kinetic energy E and as they approach the interaction region they acquire a potential energy. Let the potential energy