1. INTRODUCTION

1.1. FEW BODY ASPECT OF THE ALPHA DEUTERON SYSTEM

Few body interactions are being studied both theoretically and experimentally for the last twenty years to investigate nuclear forces. Most of the earlier work had been on the three nucleon subsystem. The alpha deuteron system, one of the more recent additions to few body physics, is now considered an interesting three body system since at low energies, alpha is assumed to be a single particle (structureless boson). Experimentally, the alpha deuteron system is very easy to investigate since below alpha break up threshold only one break up channel is open, viz., $\alpha + d \rightarrow \alpha + p + n$. The reaction products ($\alpha, p, n$) are all distinguishable and one of them, $\alpha$, has no spin. Then the theoretical treatment is also simpler than that in case of nucleon-deuteron break up.
1.2. ROLE OF KINEMATICS IN SCATTERING AND BREAK UP PROCESSES

Kinematics plays an important role in understanding the dynamics of few body systems. The kinematic aspects of such systems will be discussed in Chapter II. As explained in Chapter II, in case of two body elastic scattering, the scattering angle of the outgoing particle is sufficient to determine the kinematical situation whereas in a break up experiment whether it is a nucleon-deuteron or alpha-deuteron system, one has to detect two particles in coincidence to select a specific kinematical condition. This is called a kinematically complete experiment which gives a detailed information about the physical scattering process. By choosing appropriate pairs of correlation angles in which two particles are detected, certain interesting regions of three body phase space can be selected. Quasifree scattering (QFS) and final state interactions (FSI) are the well known regions studied for a long time.

1.2.1. Quasifree Scattering (QFS)

This is a quasi two body process in the sense that the incoming nucleon (say '1') is assumed to interact with only one of the constituents of a bound system like (2,3), the other particle acting as a spectator.

The reaction: $1 + (2,3) \rightarrow 1 + 2 + 3$

The scattering is called quasifree scattering because the interacting nucleon is bound and some energy has to be transferred to the other nucleon in order to break up the bound system. Because of
the relatively small binding energy of the deuteron (i.e., proton and neutron are very weakly bound), this is easily done even at low projectile energies and the quasifree scattering is observed as a pronounced peak in the differential cross section.

1.2.2. Final State Interaction (FSI)

Particles produced in a nuclear reaction often interact strongly with each other before getting outside the range of their mutual forces. These interactions are termed as final state interactions which are expected in the kinematic region (called FSI region) where two of the three particles in the final state find themselves left in a low relative momentum state (or low relative energy). This interaction has a strong influence not only on the angular distributions but also on the energy spectra of the secondary particles.

1.2.3. Coulomb Effect

The Coulomb interaction is expected to affect the differential cross section strongly when q\(p\) energy (in case of \(Qd\) system) is nearly zero, which needs that both detectors are placed on the same side of the beam. Fig. 1.1 shows\(^1\) that q\(p\) energy is close to zero in the arc length energy interval 3-4 Mev and the experimental cross section is very small, which was expected to be due to Coulomb repulsion.
Figure 1.1:

Arc projected spectrum where both detectors were placed on the same side of the incoming beam

—— Coulomb correction considered

---- α-p energy.
Fig. 1.1
1.2.4. Three Body Interaction

The symmetric point where particles scatter with small relative energies has been considered as suitable regions to study possible influence of three body forces, if any. Evidence of possible three body forces has been claimed by Das Gupta et al.

Thus several kinematical situations can be selected according to our interest. We will concentrate on the FSI regions.

1.3. THEORETICAL BACKGROUND

1.3.1. Elastic Scattering

Theoretical study of the two body elastic scattering has been done in various ways by several workers. The phase shift analysis of the elastic angular distributions seems to be a powerful method to obtain information about the excited states of nuclei formed by the projectile and the target. The method adopted mainly by the Zürich group has become extremely successful for the d-α scattering preferably below $E_{lab} < 20$ Mev. The analysis is accomplished by assuming phase shifts at a given energy, which allows the differential cross section to be calculated. These calculated values are then compared to the measurements in order to compute changes in the phase shifts necessary to obtain a better fit. By iterating this process, final values for the phase shifts are determined and presented graphically. The single level
approximation of R-matrix theory\(^{12}\) is used to extract level parameters of the excited states of the compound nucleus from the derived phase shifts. At higher energies, higher order phases are required, which makes extraction of phase shifts from measured cross sections extremely difficult. Gammel, Hill and Thaler\(^{10}\) have developed a model for \((d+\alpha)\) interaction assuming that the nucleons in the deuteron interact with the \(\alpha\)-particle (treated as a fundamental particle below \(\alpha\)-break up threshold) through the optical model potential and between themselves through the \(N-N\) potential. With this potential formalism, they calculated phase shifts of the experimental data on elastic scattering of deuterons on alpha up to 4.5 Mev and also at 8 Mev and 10.3 Mev and obtained a good theoretical fit without considering the distortion of the deuteron wave function and deuteron break up during the interaction. Deuteron break up effects were suggested to be important in the 20-30 Mev lab. energy region. The high cross section for the \((d,p)\) process\(^{13}\) in \(^4\)He\((d,p)\)^5He together with the strong decrease of the elastic cross section for recoil process strongly supported the need of deuteron break up in the theoretical approach of Gammel et al\(^{10}\).

Attempts\(^{11,14}\) to solve the \(d-\alpha\) scattering problem correctly have been made by means of Faddeev's two dimensional coupled integral equations. These attempts are based on the usual formalism of Faddeev by means of scattering amplitudes and Green's functions given in momentum space. Interactions have simple forms in this space, particularly sums of separable terms. Shanley\(^{14}\) (S) used Amado's quasiparticle formalism\(^{15}\) for the \((N-N-\alpha)\) system.
Coulomb effects were neglected and three particles were assumed to interact by pairs through separable interactions of the Yamaguchi type\cite{16,17}. The N-N system was described by $^1S_0$ and $^3S_1$ partial waves while some calculations include the D-state of the deuteron. The parametrizations used are those of Phillips\cite{18}.

The N-α interaction proceeds through the $S_{1/2}$, $P_{1/2}$ and $P_{3/2}$ partial waves and only $S_{1/2}$ interaction is repulsive. The agreements with experiments were not so good. Ghovanlou and Lehman\cite{19}(GL) used various combinations of existing interactions in their $^6$He ground state calculations. But neither S nor GL parametrizations produced theoretical phase shifts which are in good agreement with n-α experimental data in all the energy range. Charnomordic et al\cite{11} carried out a similar calculation on d-α elastic scattering with better two body potentials and got a better agreement than Shanley's. They constructed new one term separable interaction (denoted CFL) for $S_{1/2}$, $P_{1/2}$ and $P_{3/2}$ partial waves having the form factor\cite{11},

$$g_L(p) = \frac{p^L(1+\gamma L^2)}{\prod_{j=0}^{L+1} (1 + \beta_j p^2)}$$

The $\beta$ and $\gamma$ parameters are determined by a least square fit of the experimental data. Fig. 1.2 shows the comparison between CFL, S and GL phase shifts. Obviously CFL interactions lead to the best fit of Satchler's data\cite{20} on phase shifts for each partial wave.
Figure 1.2:

Theoretical N-Q phase shifts

— CFL parametrizations

—- S parametrizations

—- GL parametrizations

Experimental values are from ref. 20.
Fig. 1.2
1.3.2. Three Body Break Up

It is almost impossible to solve the three body problem exactly without making some approximations. In impulse approximation (on the energy shell), three body problem is reduced to a superposition of two body problems where two scattering centres ('n' and 'p' of deuteron) are assumed to act with the incident nucleon independently and suddenly. This approximation is remarkably successful in reproducing the experimental data at high energies but fails miserably in the lower energy region. Corrections for multiple scattering, uncertainty in the deuteron d-state contribution and off-energy shell effects are seen to be important in the lower energy region. The modified impulse approximation (MIA) developed by Nakamura\(^\text{21}\) gave a good fit to the data at \(E_{\text{lab}} = 29.2\) Mev, 42 Mev and other higher energies but was found insufficient to explain the data\(^\text{22,23}\) at \(E_{\text{lab}} \leq 18\) Mev. It was Faddeev who developed a rigorous theory leading to the formulation of a system of coupled two dimensional integral equations for the three nucleon system. In principle being solvable, the solution of this system on a present day computer is difficult, if not impossible, without making approximations in the potential model used as input. Potential models needed to describe the two body data accurately are rather complicated. When these models are simplified for use in the three body theory as input, one has to take care about the fact that the possible discrepancy between the calculations and the experimental data must not be due to
the approximation made in the construction of the potential model. So the choice of the two body potential model is of crucial interest. Within the framework of pairwise separable two nucleon interaction, the coupled two-dimensional integral equations become one dimensional after an angular momentum decomposition, which facilitates their numerical solution considerably. With simple separable Yamaguchi potentials in $^{1S}_0$ and $^{3S}_1$ states and the assumption of charge independence of nuclear forces, qualitative agreement with the experimental data is satisfactory. Even with these approximations (neglect of higher partial waves in the interaction and assumption of charge independence) the numerical calculations are complicated and time consuming. Attempts to include the NN tensor force and P-wave interactions, the other important components of the NN interaction, were made by J. Bruinsma.

An additional problem of the pd break up and α-d break up reactions is the Coulomb interaction. It was neglected in solving the three body integral equations because of the present impossibility to include long range interactions into the Faddeev theory for break up processes. A Coulomb correction has been included in the αp system by using a strong αp interaction in the final state which reproduces the αp phase shifts. Attempts to include Coulomb correction in the integral equations have been made but produce no satisfactory results.
Chapter II deals with the kinematics of two body and three body processes and some special cases of the alpha-deuteron system. Chapter III highlights the present experimental status of the two particle and the three particle systems. Theoretical investigation comes in the IVth Chapter. Chapter V describes the proper experimental arrangement made by us, which is broadly classified into two categories depending on two types of target - gas and solid. Gas scattering arrangements, calculation of geometry factor, design and construction of a small scattering chamber and its high vacuum technique with a view to performing gas target experiment fall in the first category. A complete arrangement of the solid target experiment performed with the Variable Energy Cyclotron of Calcutta is described in the remaining part of the chapter. Analysis of the elastic data and preliminary results obtained from the alpha deuteron break up experiment are presented in Chapter VI together with some discussions.