CHAPTER VI

6. DATA ANALYSIS AND DISCUSSIONS

6.1. ALPHA DEUTERON ELASTIC SCATTERING

Figs. 6.1 and 6.2 represent carbon spectra at two detection angles. Peaks corresponding to alpha scattered from carbon elastically and inelastically (from 4.439 Mev excited state) were kinematically identified from carbon spectra for all detected angles. Table VII shows the peak channel numbers and corresponding energies obtained from kinematics. They were used for each detector to achieve the respective calibration curve by least square method. Figs. 6.3 to 6.16 show typical pulse height spectra obtained from alpha particle bombardment on deuterated polyethylene target at various laboratory angles. Deuterium peaks for all angles were kinematically...
Figures 6.1 and 6.2:

Carbon spectra at 20° and 30° detection angles. Elastic and 1st excited peaks (4.439 Mev excited state) of carbon are shown.

Target = carbon.

$E_{\alpha(\text{inc})} = 39.0$ Mev.
$\theta_{\text{lab}} = 20^\circ$
Table VII. Peak channel numbers and corresponding energies for detector calibration.

\[ E_{\alpha(inc)} = 39 \text{ Mev}, \quad \text{Target} = \text{Carbon (225 \( \mu \text{g/cm}^2 \))} \]

<table>
<thead>
<tr>
<th>Angle of detection</th>
<th>Detector of detection</th>
<th>Peak name</th>
<th>Corresponding channel number from carbon spectrum</th>
<th>Corresponding energies from kinematics (in Mev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°</td>
<td>5L1</td>
<td>C\text{elastic}</td>
<td>881.2</td>
<td>38.08</td>
</tr>
<tr>
<td></td>
<td>5L1</td>
<td>C\text{1st ex.}</td>
<td>779.95</td>
<td>33.629</td>
</tr>
<tr>
<td>20°</td>
<td>5L1</td>
<td>C\text{elastic}</td>
<td>865.6</td>
<td>37.412</td>
</tr>
<tr>
<td></td>
<td>5L1</td>
<td>C\text{1st ex.}</td>
<td>765.47</td>
<td>32.988</td>
</tr>
<tr>
<td>35°</td>
<td>5L1</td>
<td>C\text{elastic}</td>
<td>799.72</td>
<td>34.468</td>
</tr>
<tr>
<td></td>
<td>5L1</td>
<td>C\text{1st ex.}</td>
<td>702.59</td>
<td>30.174</td>
</tr>
<tr>
<td>40°</td>
<td>5L1</td>
<td>C\text{elastic}</td>
<td>772.0</td>
<td>33.235</td>
</tr>
<tr>
<td></td>
<td>5L1</td>
<td>C\text{1st ex.}</td>
<td>675.49</td>
<td>28.999</td>
</tr>
<tr>
<td>55°</td>
<td>5L1</td>
<td>C\text{elastic}</td>
<td>676.63</td>
<td>29.083</td>
</tr>
<tr>
<td></td>
<td>5L1</td>
<td>C\text{1st ex.}</td>
<td>585.77</td>
<td>25.067</td>
</tr>
<tr>
<td>30°</td>
<td>5L2</td>
<td>C\text{elastic}</td>
<td>961.0</td>
<td>35.588</td>
</tr>
<tr>
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<td>5L2</td>
<td>C\text{1st ex.}</td>
<td>853.7</td>
<td>31.243</td>
</tr>
<tr>
<td>35°</td>
<td>5L2</td>
<td>C\text{elastic}</td>
<td>935.0</td>
<td>34.468</td>
</tr>
<tr>
<td></td>
<td>5L2</td>
<td>C\text{1st ex.}</td>
<td>827.81</td>
<td>30.174</td>
</tr>
<tr>
<td>45°</td>
<td>5L2</td>
<td>C\text{elastic}</td>
<td>869.0</td>
<td>31.912</td>
</tr>
<tr>
<td></td>
<td>5L2</td>
<td>C\text{1st ex.}</td>
<td>764.0</td>
<td>27.742</td>
</tr>
<tr>
<td>50°</td>
<td>5L2</td>
<td>C\text{elastic}</td>
<td>833.0</td>
<td>30.521</td>
</tr>
<tr>
<td></td>
<td>5L2</td>
<td>C\text{1st ex.}</td>
<td>728.64</td>
<td>26.424</td>
</tr>
<tr>
<td>65°</td>
<td>5L2</td>
<td>C\text{elastic}</td>
<td>720.0</td>
<td>26.155</td>
</tr>
<tr>
<td></td>
<td>5L2</td>
<td>C\text{1st ex.}</td>
<td>618.32</td>
<td>22.316</td>
</tr>
</tbody>
</table>
Typical spectra from α-d elastic scattering
at $E_\alpha = 39.0$ Mev for various laboratory angles.
Target $= (CD_2)_n$. 
$\theta_{lab} = 10^\circ$

C-ELASTIC

ALPHA FROM DEUTERON

CHANNEL NUMBER

COUNTS PER CHANNEL
\[ \theta_{\text{lab}} = 30^\circ \]

FIG. 6.7

C-ELASTIC

C-151 EX

RECOIL DEUTERON

COUNTS PER CHANNEL

CHANNEL NUMBER
\[ \theta_{\text{lab}} = 40^\circ \]

**Fig. 6.10**
\( \theta_{\text{lab}} = 55^\circ \)

\( \text{C-ELASTIC} \)

\( \text{C-ISET EX} \)

\( \text{RECOIL DEUTERON} \)

CHANNEL NUMBER

COUNTS PER CHANNEL

FIG. 6.13
Counts per Channel

Channel Number

Alpha from Deuteron

C-Elastic

$\theta_{lab} = 22.5^\circ$
identified from the appropriate calibration curve. After identifying the deuterium peaks at various angles, peak area ($n_d$) was calculated subtracting the background. Corresponding recoil deuterium numbers from the monitor were also calculated. Fig. 6.17 shows the typical monitor spectrum for a particular run.

Differential cross section at any angle (in the laboratory system) is given by,

$$
(\sigma) \theta = \frac{n}{n_0 N \Delta \Omega}
$$

(1)

where,

- $n$ = number of particles emerging at an angle $\theta$ into a detector of solid angle $\Delta \Omega$
- $n_0$ = number of particles incident on the target
- $N$ = number of target particles/cm$^2$.

For a particular run, we can rewrite the Eq. (1) in the following way:

$$
\sigma_\theta = \frac{n_d}{n_0 N \Delta \Omega_t} \quad \text{(for any detector)}
$$

(2)

$$
\sigma_{d(M)} = \frac{n_{d(M)}}{n_0 N \Delta \Omega_M} \quad \text{(for monitor)}
$$

(3)

where,

- $\sigma_\theta$ = deuterium cross section in the laboratory system for a detector at a certain angle.
- $\sigma_{d(M)}$ = deuterium cross section in the laboratory system for monitor at the fixed angle.
Figure 6.17:

Monitor spectrum at 45° for a particular run.
\[ \mathrm{d}n_t, \ \mathrm{d}n_M = \text{solid angles of any detector selected for angular distribution and the monitor.} \]

From (2) and (3),

\[ \sigma_d = \frac{n_d}{n_d(M)} \frac{\mathrm{d}n_M}{\mathrm{d}n_t} \sigma_d(M) \tag{4} \]

If \( \sigma_d^{C.M.} \) be the deuterium cross section in the centre of mass system,

\[ \frac{\sigma_d^{C.M.}}{\sigma_d} = \frac{1}{4 \cos \theta_d} \tag{5} \]

where, \( \theta_d \) = Angle of recoil deuteron in the lab. system.

From (4) and (5),

\[ \sigma_d^{C.M.} = \sigma_d \frac{1}{4 \cos \theta_d} = \frac{1}{4 \cos \theta_d} \frac{n_d}{n_d(M)} \frac{\mathrm{d}n_M}{\mathrm{d}n_t} \sigma_d(M) \tag{6} \]

If all the right hand side quantities are known, \( \sigma_d^{C.M.} \) can be calculated at various angles and one can get a variation of \( \sigma_d^{C.M.} \) with \( \theta_d^{C.M.} \). The cross section was obtained from recoil deuterons and from observation of the scattered alpha particles. Table VIII shows the values of cross section obtained at various angles. The data were approximately 25\% - 28\% higher for 60° and 70° c.m. angles and 12\% - 14\% higher for \( \theta \) c.m. > 80° than the ones reported previously\(^{41} \) at 20.2 Mev. Statistical error for the measurement of our data was always less than 2\%.

For all the existing \( \alpha \)-d data obtained elsewhere\(^{40-42} \) (Fig. 3.1), deuterium was the projectile with alpha as target where-
Table VIII. Observed cross sections

\[ E_\alpha = 39.0 \text{ Mev.} \]

<table>
<thead>
<tr>
<th>( \theta_{\text{c.m.}} ) (degrees)</th>
<th>( \frac{d\sigma}{d\Omega} ) (mb/sr)</th>
<th>Observed particle</th>
<th>Statistical error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.168</td>
<td>814.76</td>
<td>( \alpha )</td>
<td>0.24</td>
</tr>
<tr>
<td>38</td>
<td>242.298</td>
<td>( \alpha )</td>
<td>0.339</td>
</tr>
<tr>
<td>50</td>
<td>16.255</td>
<td>( d )</td>
<td>1.8</td>
</tr>
<tr>
<td>60</td>
<td>21.621</td>
<td>( d )</td>
<td>1.16</td>
</tr>
<tr>
<td>70</td>
<td>26.295</td>
<td>( d )</td>
<td>1.03</td>
</tr>
<tr>
<td>80</td>
<td>27.489</td>
<td>( d )</td>
<td>0.74</td>
</tr>
<tr>
<td>82</td>
<td>25.327</td>
<td>( \alpha )</td>
<td>0.47</td>
</tr>
<tr>
<td>95</td>
<td>32.538</td>
<td>( d )</td>
<td>0.87</td>
</tr>
<tr>
<td>100</td>
<td>33.186</td>
<td>( d )</td>
<td>0.9</td>
</tr>
<tr>
<td>107</td>
<td>29.896</td>
<td>( d )</td>
<td>1.17</td>
</tr>
<tr>
<td>115</td>
<td>21.419</td>
<td>( d )</td>
<td>1.01</td>
</tr>
<tr>
<td>120</td>
<td>16.876</td>
<td>( d )</td>
<td>1.19</td>
</tr>
<tr>
<td>127</td>
<td>14.332</td>
<td>( d )</td>
<td>1.61</td>
</tr>
<tr>
<td>130</td>
<td>11.792</td>
<td>( d )</td>
<td>1.89</td>
</tr>
</tbody>
</table>
as we have measured cross sections for the elastic scattering $d(\alpha, \alpha)d$ where alpha was the projectile. The following two points were noted for the comparison of measured differential cross sections with some existing data at energies close to ours.

A. The deuteron energy, $E_d$, in $\alpha(d,d)\alpha$ scattering gives the same centre of mass energy as $2E_d$ Mev alpha particles in the $d(\alpha, \alpha)d$ scattering.

B. The recoiling deuterons in $d(\alpha, \alpha)d$ elastic scattering were counted at an angle $\theta_d$, corresponding to $2\theta_d$ in the centre of mass system referring to the incoming alpha particle. In $\alpha(d,d)\alpha$ elastic scattering, all angles are referred to the incoming deuteron and the centre of mass angle of the deuteron in our case will be $(180^\circ - 2\theta_d)$.

Fig. 6.18 shows the angular distributions of differential cross sections of the present experiment$^{105,106}$ on alpha deuteron elastic scattering in the centre of mass system compared with those of two earlier deuteron-alpha experiments$^{7,42}$ at nearby c.m. energies. Data show good resemblance to the earlier data$^{7,40-42}$ with an enhancement in cross-sections between $70^\circ$ and $90^\circ$ c.m. angles the position and height of which changes with energies. The fits are due to charmonomic's Faddeev type calculations which are based on CFL parametrizations for N-$\alpha$ interactions and ACS4 for the $^3S_1-^3D_1$ wave (as described in sections 4.2.1A and 4.2.1B).

Calculated differential cross-sections are seen to be in good agreement with experiments at c.m. energies close to ours.
Angular distributions of differential cross sections for alpha deuteron elastic scattering in the centre of mass system for the present experiment compared with those of two earlier d-α experiments (7,42) at nearby c.m. energies. The fits are due to Charnomordic's (11) Faddeev type calculations. The dash dot (---) line represents the polynomial fit of the present data.
Fig. 6.18

- : dσ elastic data at 21 MeV
- : dσ elastic data at 17 MeV
- : Present data

- CHARNOMORDIC'S FIT AT 21 MeV
- CHARNOMORDIC'S FIT AT 17 MeV
- POLYNOMIAL FIT OF THE PRESENT DATA
6.1.1. Polynomial Fit of the Present Data

The scattering process can be represented by spherical polar co-ordinates and obviously may be expressed by Legendre polynomials. The experimental data here in the angle region $50^\circ \leq \theta_d \leq 100^\circ$ fit well (Fig. 6.18) with a polynomial assumed as,

$$
\left( \frac{d\sigma}{d\theta} \right)_{c.m.} = \left[ P_3(\cos \theta_d^c.m.) + P_4(\cos \theta_d^c.m.) + C \right]^2
$$

(7)

C is a constant added to normalise the calculated values with the experimental cross section and was found to be $C = 5.268$.

6.2. PRELIMINARY RESULTS OF $\alpha$-d BREAK UP EXPERIMENT

A two dimensional print out from Canberra-88 MCA between alpha and proton energies corresponding to each event of coincidence between alphas and protons arising from deuteron break up was obtained. This two parameter data showed enhancement at kinematically calculated positions along the kinematic arc. During the run for this two parameter spectrum deuteron from the elastic scattering $d(\alpha, \alpha)d$ were counted in a separate monitor detector placed at $40^\circ$ for normalizing the break up data. But the correlation cross sections along the arc of the kinematic locus became very low due to the non-availability of enough beam time and the analysis could not be performed.
6.3. DISCUSSIONS

As described in section 3.1.C, the earlier existing data in the energy region 19-25 Mev are seen to be not fully reliable and possess remarkable energy dependence at the same time over a specified angular region. One therefore needs a good amount of accurate data in this energy region. The present experiment was performed as a part of our project studying alpha deuteron break up at incident alpha energies between 30 Mev and 90 Mev. The marked enhancement in differential cross sections between 70° and 90° c.m. scattering angles is most prominent at energies close to that of the present experiment and had been tried to understand in the light of Faddeev type calculations\textsuperscript{11).} The present data are being analysed with the help of such calculations.

As regards $E_p - E_d$ kinematic plot\textsuperscript{107) }obtained from α-d break up experiment using a very simple electronics set up (described in section 5.2.6B) having no fast output from the preamplifiers, the results indicate some interesting features concerning possible two body final state interactions as viewed from distinct enhancements at some kinematically calculated positions along the arc of the kinematic locus. An experiment with a set up considering the fast side of the coincidence electronic logic and an on-line computer (NORSK DATA) for data acquisition recently installed in the Variable Energy Cyclotron Centre, Calcutta, is in progress.