INTRODUCTION

We have many problems relating to the study of the interactions of elementary particles which could be studied with more incisive understanding by considering one of the particles participating in the interaction in a bound state like a nucleon inside an atomic nucleus than when all the particles are free before and after the collision. Besides this the elementary particle interactions with nuclei would also be interesting for comparison of the experimental data with the theoretical calculations which are made within the framework of some nuclear model from the point of view of checking the model itself.

In this thesis we have taken up several problems related to photomeson production on a nucleon at low as well as at high energies and have discussed the utility of using nuclear targets in the place of a free nucleon in the elastic as well as in the inelastic channels i.e.,

\[ \gamma^* A \rightarrow A + \pi^0 \quad \text{(Elastic)} \]
\[ \gamma^* A \rightarrow A^* + \pi^0 \quad \text{(Inelastic)} \]

to study several problematic features relating to

\[ \gamma^* N \rightarrow N + \sigma^0 \]

interaction.

For example, in the study of low energy \( \sigma \)-meson photoproduction on nucleon we consider the problems
regarding (1) the determination of multipole amplitudes, 
(2) the determination of the quantities $I_0/C$ and the 
asymmetry ratio $\Sigma$, (3) the determination of the threshold 
pion-nucleon charge exchange scattering length and (4) the 
test of the quark model, etc. and have investigated these 
problems through appropriate nuclear reactions which 
yield interesting results. In fact, we have suggested 
methods to empirically determine (1) the multipole ampli-
tudes at near-threshold region and above near-threshold 
energy region, (2) the quantity $I_0/C$ and $\Sigma$ with unpola-
rized photons at near threshold energy region, (3) the 
threshold scattering length for pion-nucleon charge exchange 
reaction and have also suggested a more reliable method 
to test the quark model by determining the $E_{1+}$ amplitude 
in an empirical way at the $3\pi^-$ resonance region.

Not only at low energy but also at high energies 
we note the fruitfulness of studying nuclear phenomena, for 
example, in the study of individual Regge trajectories 
which will not be possible if we consider the production 
process on nucleon, because in such reactions many Regge 
trajectories will enter into the amplitude and the parame-

trization will involve many uncertainties.

Regarding the comparison of the experimental data with the theoretical calculations within the framework of a nuclear model we have discussed the photoproduction of \( \pi^0 \) meson on \( ^7\text{Li}, ^9\text{Be}, ^{12}\text{C}, \text{and} ^{16}\text{O} \) assuming I-S coupling shell model at low energy using different dynamical amplitudes due to Chew et al., Berends et al., Schwela and (CGIM(Roper)) as well as at high energy with Regge cut Model — this is all the more important since a theoretical description of the nuclear photoproduction entails considerable difficulties.

As to the next interest of this thesis we have put forward a \( \rho \) and \( \rho' \) trajectory exchange model for \( \rho^0 \) photoproduction on carbon at high energies where assumption was made to consider the carbon nucleus as an elementary particle with spin-parity \( 0^+ \) and quite interestingly we find that our model gives a good fit to the experimental data.

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data and predicts the experimental fact that \( \frac{d\sigma}{d\Omega} \) at \( t = 0 \) decreases with increase of energy.

Besides the above problems we have further suggested in this thesis methods (1) to determine empirically the nuclear form factors of \( ^7\text{Li} \), \( ^9\text{Be} \), \( ^{12}\text{C} \) and \( ^{16}\text{O} \) which involve considerable uncertainties due to the nuclear radius parameter \( r_0 \); (2) to determine the spin parity of the second excited state in \( ^7\text{Li} \) whose spin-parity is ambiguous, being \( \leq 7/2^- \), and have also investigated the role of the \( \omega \) and \( \xi \) exchange mechanisms in the nuclear photoproductions. (10)

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In Chapter I we have discussed the photoproduction of meson on $^{7}\text{Li}$, $^{9}\text{Be}$, $^{12}\text{C}$ and $^{16}\text{O}$ assuming L-S coupling shell model, and impulse approximation in the elastic as well as in the inelastic channels. Using oscillator wave functions to calculate the form factors and computing the dynamical quantities using the different values of the amplitudes—the old OGLU amplitude calculated with Roper phase shift (11), the multipole amplitudes due to Chew et al. (12), Schwela (13) and Berends et al. (14), we obtained best $\chi^2$ fits with the experimental values at 160 MeV which correspond to the following values of the nuclear radius parameter $r_0$: $r_0 = 1.2$ fm ($R = 2.30$ fm) for $^{7}\text{Li}$, $r_0 = 1.1$ fm ($R = 2.29$ fm) for $^{9}\text{Be}$, $r_0 = 1.1$ fm ($R = 2.51$ fm) for $^{12}\text{C}$ and $r_0 = 0.9$ fm ($R = 2.26$ fm) for $^{16}\text{O}$. The best $\chi^2$ values using the different amplitudes vary from 6 to 11 in the case of $^{7}\text{Li}$ where the number of experimental points is 9 and the value of the nuclear radius obtained is in good agreement with other sources. The lowest value of $\chi^2$ corresponds to the use of the amplitudes of Berends et al. (14).

As has been pointed out in ref. (14) at very low energy (like 160 MeV in our case) there is a discrete discrepancy between theory and experiment. Therefore the values obtained at very low energies from theory:

(13) D. Schwela, Unpublished thesis.
<table>
<thead>
<tr>
<th>$s = 0$</th>
<th>$s = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda = 2$</td>
<td>$\lambda = 1$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>$\tau$</td>
</tr>
<tr>
<td>$l = 2$</td>
<td>$l = 0$</td>
</tr>
<tr>
<td>$0$</td>
<td>$\frac{1}{25} \sqrt{2}$</td>
</tr>
<tr>
<td>$\frac{38}{25} \sqrt{2}$</td>
<td>$\frac{1}{3} \sqrt{5}$</td>
</tr>
</tbody>
</table>

Table 7: The Reduction factors $R$ for elastic processes on $^8\text{Be}$.
Table 8
The reduction factors \( R_{\lambda} \) for inelastic process on \(^9\)Be leading to the second excited state at 2.43 MeV.

<table>
<thead>
<tr>
<th>( t )</th>
<th>( s = 0 )</th>
<th>( s = 0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda = 2 )</td>
<td>( \frac{7}{25\sqrt{6}} )</td>
<td>( \frac{\sqrt{7}}{375\sqrt{2}} )</td>
</tr>
<tr>
<td>( \lambda = 1 )</td>
<td>( \frac{14}{225} ) ( \sqrt{\frac{2}{3}} )</td>
<td></td>
</tr>
<tr>
<td>( \lambda = 2 )</td>
<td>( \frac{7}{375\sqrt{6}} )</td>
<td></td>
</tr>
<tr>
<td>( \lambda = 3 )</td>
<td>( 0 )</td>
<td>( 0 )</td>
</tr>
</tbody>
</table>
If we assume a pure L-S coupling shell model for $^9$Be the coefficients $A$, $B$ and $C$ appropriate to the $p$ shell calculations are given in Table 1 while the relevant reduction factors for elastic production are given in Table 7. An interesting inelastic transition in the case of $^9$Be is to the second excited state at 2.43 MeV with spin parity $5/2^-$. Since the ground state is $3/2^+$, this transition can go only via the spin-dependent amplitude. Assuming again a pure L-S coupling description for the excited state the relevant reduction factors for the transition are shown in Table 8. The expressions that we obtain for the elastic and the inelastic transitions are given below:

Elastic

\[ |Q|_L^2 = \left[ (4F_{2s} + 5F_{2p}) + \left( \frac{2}{5}F_{2p} \right)^2 \right] LL^* \]

\[ |Q|_K^2 = \left[ \frac{5}{7}F_{2p}^2 + \frac{3}{7} \left( \frac{4}{5}F_{2p} \right)^2 \right] (k_n \cdot k_n^*) - \frac{8}{45}F_{2p}F_{2p} \left( k_p \cdot k_p^* \right) + \frac{8}{75}F_{2p}^2 |k \cdot k_n|^2 + \frac{8}{15}F_{2p}F_{2p} |k \cdot k_p|^2 \]
Inelastic leading to $^3_1^{22} P_{3/2}$ state

\begin{align*}
(1.18) \quad |Q|_L^2 &= \frac{36}{25} F_{2p}^2 LL^* \\
(1.19) \quad |Q|_K^2 &= \left( \frac{4}{9} F_{2p}^2 + \frac{7}{25} F_{1p}^2 + \frac{2}{15} F_{0p} F_{2p} \right) \left( \hat{k}_p \cdot \hat{k}_p^* \right) - \\
&\quad - \left( \frac{6}{25} F_{2p}^2 + \frac{2}{25} F_{0p} F_{2p} \right) \left| \hat{k}_p \cdot \hat{k}_p^* \right| \\
\end{align*}

Inelastic leading to $^3_1^{22} P_{7/2}$ state:

\begin{align*}
(4.20) \quad |Q|_L^2 &= \left( \frac{74}{15} F_{3p} \right)^2 LL^* \\
(4.21) \quad |Q|_K^2 &= \left( \frac{74}{45} F_{3p} \right)^2 \left[ \frac{13}{21} \left( \hat{k}_p \cdot \hat{k}_p^* \right)^2 - \frac{4}{21} \right] \\
\end{align*}

Inelastic leading to $^3_1^{42} P_{3/2}$ state:

\begin{align*}
(1.22) \quad |Q|_L^2 &= \left| Q \right|_K^2 = \left( \frac{520}{81} F_{2p}^2 - \frac{25}{81} F_{1p} F_{2p} + \frac{845}{81 \times 4} F_{2p}^2 \right) \left( \hat{k}_p \cdot \hat{k}_p^* \right) + \\
&\quad + \frac{5}{72} \left| \hat{k}_p \cdot \hat{k}_p^* \right| \\
\end{align*}

\[ \hat{k}_1 = \frac{1}{2} \left( \hat{k}_p - \hat{k}_n \right) \]

the suffixes p or n on the dynamical quantities denote production on proton or neutron. The notations are same
Table 6

The Reduction factor $R_{\text{inelastic}}$ for the inelastic process on $^{7}\text{Li}$ leading to the excited state $^{21}_2\text{P}_{3/2}$.

<table>
<thead>
<tr>
<th>$s$</th>
<th>$\lambda = 0$</th>
<th>$\lambda = 1$</th>
<th>$\lambda = 2$</th>
<th>$\lambda = 3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$l = 0$</td>
<td>$l = 0$</td>
<td>$l = 2$</td>
<td>$l = 2$</td>
</tr>
<tr>
<td>0</td>
<td>$-\frac{2}{3}$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>$\frac{-10\sqrt{5}}{27}$</td>
<td>$\frac{\sqrt{5}}{108}$</td>
<td>$\frac{5}{216}$</td>
</tr>
</tbody>
</table>
Table 3
The reduction factor $R_{\lambda\lambda'\tau}$ for the inelastic process on $^7\text{Li}$ leading to the excited state $[3]^{22}_{22}$.

<table>
<thead>
<tr>
<th>$\tau$</th>
<th>$s = 0$</th>
<th>$s = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda = 1, \lambda = 2$</td>
<td>$\lambda = 1, \lambda = 2$</td>
</tr>
<tr>
<td>$\lambda = 0$</td>
<td>$1 = 0, 1 = 2$</td>
<td>$1 = 2$</td>
</tr>
<tr>
<td>$\lambda = 1$</td>
<td>$\frac{2\sqrt{2}}{9}, \frac{1}{15\sqrt{2}}, \frac{1}{5\sqrt{2}}$</td>
<td>$\frac{1}{15\sqrt{2}}, \frac{1}{5\sqrt{2}}$</td>
</tr>
<tr>
<td>$\lambda = 2$</td>
<td>$\frac{1}{5\sqrt{2}}$</td>
<td>$\frac{1}{5\sqrt{2}}$</td>
</tr>
<tr>
<td>$\lambda = 3$</td>
<td>$\frac{1}{3}$</td>
<td>$\frac{2\sqrt{2}}{9}$</td>
</tr>
<tr>
<td>$\lambda = 4$</td>
<td>$\frac{3}{5}$</td>
<td>$\frac{2\sqrt{2}}{9}$</td>
</tr>
<tr>
<td>$\lambda = 5$</td>
<td>$\frac{2\sqrt{2}}{9}$</td>
<td>$\frac{1}{15\sqrt{2}}, \frac{1}{5\sqrt{2}}$</td>
</tr>
</tbody>
</table>
Table 4

The reduction factor $R_{\lambda \mu \sigma r}$ for the inelastic process on $^7$Li leading to the excited state $[^3] 2^2 F_{5/2}$.

<table>
<thead>
<tr>
<th>$r = 2$</th>
<th>$s = 0$</th>
<th>$s = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda = 1$</td>
<td>$\lambda = 2$</td>
<td>$\lambda = 3$</td>
</tr>
<tr>
<td>0</td>
<td>$\frac{-37\sqrt{2}}{135}$</td>
<td>$\frac{37\sqrt{7}}{135\sqrt{15}}$</td>
</tr>
<tr>
<td>1</td>
<td>$\frac{-37\sqrt{2}}{405}$</td>
<td>$\frac{37\sqrt{7}}{135\sqrt{15}}$</td>
</tr>
</tbody>
</table>
Table 5

The reduction factor $R_{\text{M.o.}}$ for the inelastic process on $^7\text{Li}$ leading to the excited state $^3\text{P}^0_{7/2}$:

<table>
<thead>
<tr>
<th>$l = 2$</th>
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<tr>
<td>$\ell$</td>
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<tr>
<td>$1$</td>
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</tbody>
</table>
Table 1

The coefficients \( A, B \) and \( C \) appropriate to L-S coupling calculations in p-shell (3).

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>0</th>
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<th>2</th>
<th>3</th>
</tr>
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<tbody>
<tr>
<td>( l = l' = 0 )</td>
<td>( A = 1 )</td>
<td>( B = 5 )</td>
<td>( C = 9 )</td>
<td>( B = -5 )</td>
</tr>
<tr>
<td>( l = 1, l' = 2 )</td>
<td>( A = 10 )</td>
<td>( B = 15 )</td>
<td>( C = -15 )</td>
<td>( B = 5 )</td>
</tr>
<tr>
<td>( l = 2; l' = 0 )</td>
<td>( 0 )</td>
<td>( 1 )</td>
<td>( 2 )</td>
<td>( 3 )</td>
</tr>
</tbody>
</table>
Table 2

The reduction factors $R^{\lambda\lambda\tau\tau}$ and $R^{\lambda\lambda't}$ for elastic scattering on $^7\text{Li}$ in pure $L-S$ coupling

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\tau$</th>
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<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>$\frac{3}{5\sqrt{2}}$</td>
</tr>
<tr>
<td>1</td>
<td>$\frac{1}{3}$</td>
<td>$\frac{1}{5\sqrt{2}}$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\lambda'$</th>
<th>1</th>
<th>$\sqrt{\frac{1}{9}}$</th>
<th>$\frac{1}{15\sqrt{5}}$</th>
<th>0</th>
<th>$\frac{\sqrt{7}}{5\sqrt{10}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{\frac{5}{9}}$</td>
<td>$\frac{1}{15\sqrt{5}}$</td>
<td>0</td>
<td>0</td>
<td>$\frac{\sqrt{7}}{5\sqrt{10}}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\lambda'$</th>
<th>1</th>
<th>$\sqrt{\frac{1}{9}}$</th>
<th>$\frac{1}{15\sqrt{5}}$</th>
<th>0</th>
<th>$\frac{\sqrt{7}}{5\sqrt{10}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sqrt{\frac{5}{9}}$</td>
<td>$\frac{1}{15\sqrt{5}}$</td>
<td>0</td>
<td>0</td>
<td>$\frac{\sqrt{7}}{5\sqrt{10}}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
amplitude $L$ while the second term contains the contributions from the spin dependent amplitude $K$.

First we consider the $^7$Li for elastic and inelastic transitions leading to the first two excited states and also to the isobaric quartet state at 11.13 MeV. While the first excited state is assigned (6) the spin-parity $\frac{3}{2}^-$, the spin assignment for the second excited state is ambiguous and expected to be $\leq \frac{7}{2}$ and the parity is considered to be negative.

If we assume the $I-S$ coupling shell model to hold, this level is expected to have a spin-parity assignment either $\frac{5}{2}^-$ or $\frac{7}{2}^-$, if excited configurations are not considered. Although the current value (7) of 45 mb of the quadrupole moment for $^7$Li would seem to demand considerable admixture of excited configurations (8) including excitations of a particle from the $1s$ state (9,10), the latest electron scattering studies (11) support a simple $I-S$ coupling description using oscillator wave functions. We shall, therefore, assume the ground state to be pure $[4,3] (1s)^4 (1p)^{22} P_{3/2}$ state. The first excited state is taken to be $[4,3] (1s)^4 (1p)^{32} P_{1/2}$, while the alternative assignments of $[4,3] (1s)^4 (1p)^{32} P_{7/2}$ are considered for the second state.


(9), (10), (11) - page 29.
The quartet state at 11.13 MeV is assumed to be $[4,21]$

$$(1s)^4 (1p)^3 \Phi_{3/2}^{42}.$$

The coefficients $A$, $B$ and $C$ appropriate to $p$-shell calculations are given in Table 1 and the relevant reduction factors for the elastic case and for the excited state transitions are given in Tables 2-6 respectively, leading to the following expressions:

Elastic

\[
|Q|_L^2 = \left[ (4 F_{0s} + 3 F_{1p})^2 + \left( \frac{2}{5} F_{2p} \right)^2 \right] LL^x
\]

\[
|Q|_k^2 = \left( \frac{5}{7} F_{0p}^2 - \frac{1}{15} F_{0p} F_{1p} - \frac{1}{35} F_{2p}^2 \right) (\vec{k} \cdot \vec{p}_e)^2 + \left( \frac{6}{25} F_{2p}^2 + \frac{2}{5} F_{1p} F_{2p} \right) (k \cdot \vec{p}_p)^2
\]

Inelastic leading to $[3]^{22}F_{5/2}$ state

\[
|Q|_L^2 = 6 \left( \frac{37}{45} F_{2p}^2 \right) LL^x
\]

\[
|Q|_k^2 = \frac{2}{21} \left( \frac{37}{45} F_{2p}^2 \right)^2 \left[ 2 \left( \vec{k} \cdot \vec{p}_e \right) + \delta \left( \vec{k} \cdot \vec{p}_p \right)^2 \right]
\]

(8) R.D. Present, Phy. Rev. 139 (1965) B 300


The differential cross-section for the photo-production of neutral pions on nuclei can be written (in natural units $\hbar = c = $ pion mass = 1 ) as

\[
(1.1) \quad \frac{d\sigma}{d\Omega} = \frac{\varphi}{2\nu} \sum |Q|^2
\]

where $(\nu = |\vec{p}|, \vec{p}')$ denotes the energy and momentum of the incident photon, $\epsilon$ its polarization and $(\vartheta_o, \varphi_o)$ the energy and momentum of the emitted pion which we shall assume to be given by

\[
(1.2) \quad \varphi^2 + 1 = \nu
\]

and $|Q|^2$ has the form

\[
(1.3) \quad |Q|^2 = \delta_{\epsilon\epsilon'} |Q|_{\epsilon,\epsilon'}^2 + \eta^2 [J_{\xi}]^2 [J_{\xi}']^2 \chi
\]

\[
\times [\tau \Gamma_1 \Gamma_\tau] \sum_\lambda [\lambda]^{-2} R_{\lambda,\tau,\tau'} |F_\lambda|^2 A_\lambda \Lambda_\tau L^*_{\tau'} +
\]

\[
\times \sum_\ell,\ell' (i)^{l-l'} R_{\lambda,\tau,\tau';\ell,\ell'} F_{\ell} F_{\ell'}^* \left\{ B_{\ell,\ell'}(\vec{k}_\tau \cdot \vec{k}_{\tau'})^* +
\]

\[
+ C_{\ell,\ell'}(\vec{k}_\tau)(\vec{k}_{\tau'})^* \right\}
\]

where

\[
(1.4) \quad R_{\lambda,\lambda',\tau,\tau'}^{(\nu)} = R_{\lambda,\lambda} \sigma_{\tau} R_{\lambda,\lambda} \sigma_{\tau'}
\]
\begin{align}
(1.5) \quad R^{(2)}_{\lambda, \tau, \nu', \nu} &= R_{\lambda \nu} R_{\lambda \nu'}.

\left| Q \right|_{\epsilon, \lambda}^2 \text{ arising due to the participation of closed shells is given by}
\begin{align}
(1.6) \quad \left| Q \right|_{\epsilon, \lambda}^2 &= \left| \sum_{j} \eta_j \frac{1}{2} \left( l_p + l_n \right) F_{0j} \right|^2 + 2 \text{Re} \left\{ \sum_{j} \eta_j \frac{1}{2} \left( l_p + l_n \right) F_{0j} \right\}^* \times \left\{ \eta \sum_{T} C \left( T_c, T_f ; M_{T_c}, M_{T_f} \right) \left[ \epsilon \right] L_c F_0 R_{000r} \right\}.
\end{align}

In the case of L-S coupling the reduction factors R are given by
\begin{align}
(1.7) \quad R^{L-S}_{\lambda, \lambda'} &= \left[ \begin{array}{cc} L_c & L_f \\ S_c & S_f \end{array} \right] \sum_{\alpha' L'S'T'} U \left( T_{\frac{1}{2}}, T_f, T_c ; T_{\frac{1}{2}} \right) U \left( L_c, L_f, L_c ; S_c, S_f, S_c \right) \times
\langle \left( L' \right) \left( \alpha' L'S'T' \right) L_f, S_f, L_f ; S_f \left( L_c \right) \left( \alpha_f \right) \left( L_c \right) \rangle \times
\langle \left( L_f \right) \left( \alpha_f L' S' T' \right) S_f, \alpha_f L_f S_f, T_f \rangle^*.
\end{align}

where
\begin{align}
(1.8) \quad \left[ \begin{array}{ccc} L_c & L_f \\ S_c & S_f \\ T_c & T_f \end{array} \right] &= \left[ \begin{array}{c} L_f \\ S_f \\ T_f \end{array} \right] \left[ \begin{array}{c} S_f \\ T_f \end{array} \right] \left[ \begin{array}{cc} \lambda & \lambda' \\ \lambda & \lambda' \end{array} \right] \left[ \begin{array}{c} L_c \lambda \lambda' \\ S_c \lambda \lambda' \\ T_c \lambda \lambda' \end{array} \right] \left[ \begin{array}{c} L_c \lambda \lambda' \\ S_c \lambda \lambda' \\ T_c \lambda \lambda' \end{array} \right]^{-1}.
\end{align}

the notation throughout is same as in ref. (3).
The coefficients $\lambda$, $\delta$, and $\gamma$ are given by

\[(1.7) \quad A^\mu = \left[ \frac{d}{dx} \right]^2 \left[ \frac{d}{dy} \right]^2 \left[ \frac{d}{dz} \right]^4 C(z; \lambda, \gamma, \delta)
\]

\[(1.10) \quad B_{\lambda, \mu}^\nu = \delta_{\lambda, \mu} \left[ \frac{d}{dx} \right]^2 \left[ \frac{d}{dy} \right]^2 \left[ \frac{d}{dz} \right]^2 \left[ \frac{d}{dt} \right]^2 \nu \]

\[(1.11) \quad C_{\lambda, \mu, \nu} = \frac{3\sqrt{3}}{2\pi} (-1)^\lambda \left[ \frac{d}{dx} \right]^2 \left[ \frac{d}{dy} \right]^2 \left[ \frac{d}{dz} \right]^2 \left[ \frac{d}{dt} \right]^2 \nu \]

\[\times C(z; \lambda, \gamma, \delta) C(z; \lambda, \gamma, \delta) C(z; \lambda, \gamma, \delta) W(z, \lambda, \gamma, \delta)
\]

$F_d$, $F_{d'}$, $F_2$, and $F_{d''}$ are the radial integrals:

\[(1.12) \quad F_d = F_{d'} = \int_0^\infty U_j^\ast (r) U_k (r) U_j (r) dr
\]

We shall write

\[(1.13) \quad \frac{d\sigma}{d\omega} = \left( \frac{d\sigma}{d\omega} \right)_L + \left( \frac{d\sigma}{d\omega} \right)_K
\]

where the first term on the right-hand side denotes the sum of contributions from the spin-independent
In ref. (3) a formalism based on the impulse approximation and the nuclear shell model for discussing elementary particle interactions on nuclei was outlined. Where the contributions of the nucleon spin-independent amplitude as well as the nucleon spin-dependent amplitude were taken into account. In the case of the elastic processes where the initial and final nuclear states are the same it was found that all the A nucleons in the nucleus contributed the spin-independent amplitudes, while only those nucleons (say n' in number) which are outside closed shells contributed the spin-dependent parts. On the other hand, in the inelastic processes leading to definite excited states (not involving core excitation), only the n nucleons were found to contribute spin-independent as well as the spin-dependent parts. Consequently, one would expect the contribution of the spin-dependent amplitude to be relatively more important in the case of the inelastic processes rather than in the elastic phenomena. However, experimental interest in detecting spin-dependent contributions has been evidenced in at least two papers (4,5); one in the case of elastic

(3) S. Ramachandran, Nucl. Phys. 37 (1966) 107
(4) R. A. Shreack, Phys. Rev. 140 (1965) 3897.
(5) C. C. Buccino et al., Z. Physik. 196 (1966) 103.
photoproduction of neutral pions and the other in nucleon scattering. Unfortunately the nuclei chosen by Buccino et al. are all heavy nuclei with an exceedingly large number of closed-shell nucleons to allow any spin-dependent effect to be noticeable in elastic scattering. The experimental study of Shrack was in the form of a comparative study on the targets $^7$Li, $^9$Be, $^{12}$C and $^{27}$Al where two of them have predominantly spin zero isotopes while the third has spin 5/2. The negative result of Shrack could be attributed to the fact that $^{27}$Al has as many as 16 nucleons in closed shells.

The purpose of this chapter is to study theoretically the photoproduction of neutral pions on $^7$Li, $^9$Be, $^{12}$C and $^{16}$O. In the case of $^7$Li and $^9$Be, elastic production as well as production leading to a few excited states have been studied and the relative contributions of the spin-dependent amplitude have been determined.

The first excited state at 0.48 MeV in $^7$Li is so close to the ground state that experimentally it appears difficult to resolve between the ground state and the first excited state transitions. Therefore, we also obtain a $\chi^2$ fit to the experimental data taking into account this inelastic cross-section.