2

The study is described in Sect. 4. The results are given in Sect. 5. The conclusions of the study can be found in Sect. 6.

The conclusions of the study can be found in Sect. 6.

The conclusions of the study can be found in Sect. 6.

In the following section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.

In each section we present the model and presentation of each section. The model and presentation of each section are presented in Sect. 6.
Thus we solve the Dirac equation:

\[
[-i \alpha \cdot \nabla + V_0(r) + \beta M + \beta S(r) - \frac{i f g}{2 M} \beta \alpha \cdot \nabla V_0(r) + V_{\text{Coulomb}}(r)] \psi(r) = E \psi(r),
\]

where \( V_0(r) \) and \( S(r) \) are the vector and scalar potentials felt by the hyperon. The tensor coupling term directly affects the strength of the hyperon spin-orbit interaction and therefore influences the analyzing power \( A_y \). As we will see this is especially true for the \( \Lambda \). On the other hand, we do not include the isovector \( \rho \) meson which can contribute to the \( \Sigma \) optical potential. This may be important particularly in systems with an excess of neutrons.\(^{14}\)

Since the imaginary part of the optical potential arises predominantly from processes where the projectile interacts twice with the nucleus we use for the imaginary part of the optical potential the square of the factor for the real part. This is admittedly crude but should serve as a first estimate. For pure SU(3) symmetry the imaginary part of the \( Y \)-nucleus optical potential is thus obtained by multiplying the nucleon-nucleon potential by \( a_{\Sigma Y}^2 = (2/3)^2 = 4/9 \).

When applied to bound hypernuclear systems the SU(3) values of the hyperon couplings give only a qualitative description of the experimental data. Therefore we also tried other pairs of scaling factors \( a_{\Sigma Y} \) \((i = S, V)\) adjusted to give the correct binding of hyperons in \( \Lambda \) (\( \Sigma \)) hypernuclei. In addition, this gives us an opportunity to test the sensitivity of the predictions of our model to its input. The scaling factors \( a_{\Sigma Y} \) used in our calculations are listed in table 1. The values denoted by MP are from the mean field calculation of ref. 14. The values denoted by OP were determined for each nucleus \(^{12}\)C, \(^{40}\)Ca and projectile \( \Lambda, \Sigma \) by searching for \( a_{\Sigma Y} \) consistent with existing data on hyperon binding and simultaneously choosing the SU(3) values. The fits of the \( a_{\Sigma Y} \) factors for real parts of the optical potentials were done using the geometry obtained from the global optical potential at 30 MeV. This is as low as the optical potential of ref. 9 goes and we do not expect much change in extrapolating to zero energy.

There are a number of hypernuclear mean field calculations\(^{18-23}\) in which the strength of \( \Lambda \) couplings is much smaller than the SU(3) predictions. The typical \( a_{\Lambda N} \) values used in these works lie between 1/3 and around 0.4. Therefore, for the sake of comparison we have made calculations of the \( \Lambda \)-nucleus scattering observables for values of \( a_{\Lambda N} \) close to 1/3. In all cases the imaginary optical potentials are obtained by using the squares of the factors for the real potential.

When comparing the \( a_{\Lambda N} \) values for potentials with optical model geometry with those obtained in Dirac mean field calculations\(^{14}\) we see that they are close (0.621 vs 0.618 as seen in the table entry corresponding to Fig. 1). It should be noted that this is not only the case for the targets listed in table 1 but also for the other nuclei for which we obtained an almost identical parametrization of the optical potential. This suggests that the \( r \)-dependence of the optical potential\(^{9}\) is similar to that of the mean field model\(^{14}\). Moreover, this confirms the validity of our approach since in this case we are not far from where the couplings in ref. \(^{14}\) have been determined.

The slightly larger difference between MP and OP values in the case of \(^{12}\)C reflects the fact that relativistic mean field models gives for \( a_{\Lambda N} \) 1/3 overbinding by about 1 MeV\(^{14}\).

For the \( \Sigma \) hyperon we use the parametrization close to that for the \( \Lambda \). This choice is consistent with existing information from \( \Sigma^+ \) atoms and from \( \Sigma N \) scattering\(^{23-27}\). As noted above we set the \( \rho \) coupling to zero.

For \( \Sigma \) scattering there are additional processes that affect the imaginary part of the optical potential, namely the \( \Sigma N \rightarrow \Sigma N \) charge exchange and the \( \Sigma N \rightarrow \Lambda N \) conversion in the nuclear medium. This introduces additional absorption that is not contained in the SU(3) estimates. We have investigated this effect as well and show the results in the next section.

3. Results

Calculations for the differential cross sections and analyzing powers were carried out using a modification of the program RUNT\(^{28}\) for a selection of nuclei and energies. The choice of different parametrizations, energies, projectiles and targets enabled us to investigate various features of hyperon-nucleus scattering. Here we present only results for \( \Lambda \) and \( \Sigma \) hyperon scattering off \(^{12}\)C and \(^{40}\)Ca at two different energies, 30 and 300 MeV. The sensitivity to different aspects of the calculations are demonstrated in the five figures shown. The corresponding parametrizations for each particular figure are listed in table 1.

Figure 1 shows the cross section and analyzing power for the scattering of \( \Lambda \)'s on \(^{40}\)Ca at 30 MeV for different scaling factors \( a_{\Lambda N} \) from table 1. While the MP and OP parametrizations give very close predictions of \( \sigma \) and \( A_y \) in the whole region under investigation, the SU(3) parametrization deviates significantly from them for the larger angles \( \Theta_{\text{Lab}} > 30^\circ \). The analyzing power \( A_y \) is almost 0 for each parametrization. As will be shown later this is mainly a result of tensor coupling.

The comparison of predictions for \(^{40}\)Ca and different types of projectiles at 300 MeV is made in Fig. 2. The cross sections are qualitatively similar, small deviations are caused by the different contribution of the Coulomb interaction and tensor coupling for each type of hyperon. The predictions of \( A_y \) differ considerably between \( \Sigma \) and \( \Lambda \) scattering. The difference between \( \Sigma^+ \) and \( \Sigma^- \) is not so pronounced which signals that \( A_y \) is affected far more by the tensor coupling than by the Coulomb interaction. We should point out that in other calculations we have carried out with smaller values of \( a_{\Sigma Y} \), the Coulomb potential started to play a more significant role. For the \( \alpha \)'s close to SU(2) values, the dominant effect of the tensor coupling is confirmed in Fig. 3 where we present the results for \( \Lambda \)-\(^{40}\)Ca at 300 MeV for various strengths of tensor coupling \( f / g = -1, 0, +1 \). (It is to be noted that the unrealistic value \( f / g = +1 \) is used just for comparison.) Again, cross sections are qualitatively similar for different values of \( f / g \) with maxima and minima at roughly the same angles. More significant differences for larger angles are probably experimentally inaccessible due to a decrease of the magnitude by more than a factor of 100. However, the situation changes for \( A_y \) where the predictions are strongly sensitive to the tensor coupling. Particularly for \( f / g = -1 \) we obtained quite a different result. For \( f / g = 0 \) and 1, the \( A_y \) predictions differ significantly at small angles \( (\Theta < 12^\circ) \) while for larger angles they become almost identical. The \( f / g = -1 \) (value suggested by SU(3)) leads to considerably smaller values of analyzing powers \( A_y \) is close to zero for forward angles. This result suggests that measurements of \( A_y \) would give information on the tensor coupling of the vector meson to a hyperon.

Figure 4 illustrates how the predictions of scattering observables change when
4. Condition

The experimental setup included a feedback system to monitor the experimental conditions. The system was designed to ensure accurate and consistent data collection.

References


Acknowledgment

The authors would like to acknowledge the contributions of Dr. A. B. Smith and Mr. C. D. Johnson to the development of the experimental setup. Their expertise and guidance were invaluable in the success of this project.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Line Type</th>
<th>( \alpha_Y )</th>
<th>( f/g )</th>
<th>( \alpha_S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 1. ( ^{40}\text{Ca} ) 30 MeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>solid</td>
<td>SU(3)</td>
<td>0.667</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dashed</td>
<td>MF</td>
<td>0.667</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dash-dotted</td>
<td>OP</td>
<td>0.667</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dotted</td>
<td>OP</td>
<td>0.727</td>
<td>(-1)</td>
</tr>
<tr>
<td>Fig. 2. ( ^{40}\text{Ca} ) 300 MeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Sigma^+ )</td>
<td>dashed</td>
<td>OP</td>
<td>0.667</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Sigma^- )</td>
<td>solid</td>
<td>OP</td>
<td>0.667</td>
<td>(+1)</td>
</tr>
<tr>
<td>( \Xi^- )</td>
<td>dash-dotted</td>
<td>OP</td>
<td>0.667</td>
<td>(+1)</td>
</tr>
<tr>
<td>Fig. 3. ( ^{40}\text{Ca} ) 300 MeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dashed</td>
<td>OP</td>
<td>0.667</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>solid</td>
<td>OP</td>
<td>0.667</td>
<td>(+1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dotted</td>
<td>OP</td>
<td>0.667</td>
<td>0</td>
</tr>
<tr>
<td>Fig. 4. ( ^{40}\text{Ca} ) 300 MeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dashed</td>
<td>OP</td>
<td>0.333</td>
<td>(-1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>solid</td>
<td>OP</td>
<td>0.333</td>
<td>(+1)</td>
</tr>
<tr>
<td>( \Lambda )</td>
<td>dotted</td>
<td>OP</td>
<td>0.333</td>
<td>0</td>
</tr>
<tr>
<td>Fig. 5. ( ^{12}\text{C} ) 300 MeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Sigma^+ )</td>
<td>solid</td>
<td>SU(3)</td>
<td>0.667</td>
<td>(+1)</td>
</tr>
<tr>
<td>( \Sigma^+ )</td>
<td>dashed</td>
<td>OP</td>
<td>0.667</td>
<td>(+1)</td>
</tr>
<tr>
<td>( \Sigma^+ )</td>
<td>dash-dotted</td>
<td>OP</td>
<td>0.743</td>
<td>(+1)</td>
</tr>
</tbody>
</table>