Absorption, Polarization Phenomena and Two-Baryon Interactions

Norio HOSHIZAKI and Shigeru MACHIDA

Research Institute for Fundamental Physics, Kyoto University, Kyoto
1Department of Physics, Rikkyo University, Tokyo

(Received August 21, 1962)

A study is made of polarization effects in high-energy scattering. Consideration in the limiting case of complete absorption or of the absence of real phase shifts leads to the possibility of obtaining information on two-baryon elastic interactions from polarization experiments at high energies. An approach to two-baryon interactions at close distance is briefly described.

§ 1. Introduction and statement of the problem

In an attempt to understand the structure of elementary particles, a study of two-baryon interactions at very small distance seems particularly important. The investigation of two-baryon interactions has been successfully made from the outside of the baryon during the past decade.1) We now intend to study directly the innermost region of these interactions.

In analyzing experiments on high-energy baryon-baryon scattering from this standpoint, we encounter with some difficulties. In the first place the predominance of inelastic processes causes a diffraction effect with which the elastic differential cross section is to a large extent accounted for, and thus the information on dynamical interactions between two-baryons is said to be almost unobtainable. Secondly the number of available experimental quantities in the high-energy region concerned is still quite insufficient for the complete determination of the scattering matrix.2)

In § 2 we wish to find out experimental quantities insensitive to the diffraction effect, and examine the possibility of extracting dynamical information from the results of high-energy scattering experiments.

In § 3 we will briefly discuss an approach to two-baryon interactions in the innermost region, giving a possible way out of the difficulties mentioned above.

§ 2. Polarization effects in the limit of complete absorption or in the absence of real phase shifts

We wish to obtain experimental quantities convenient for getting information on the real phase shifts. We will for this purpose give the expressions of angular distribution for the various experimental quantities in the limit of
complete absorption or in the absence of the real phase shifts. Any departure from these expressions, if observed, will indicate that real phase shifts are not zero.

We express the S matrix for elastic scattering as

\[ S = e^{2i(\theta_0 + \delta_i)} = r e^{2i\delta}, \quad r = e^{-2\delta}, \]  

(1)

and analyze it in terms of partial waves. We take

\[ S_{ij} = 0, \quad \text{for} \quad l \leq l_0, \]

\[ S_{ij} = 1, \quad \text{for} \quad l > l_0 \]

(2)

in the limit of complete absorption. Here \( l_0 \) is related to the “radius” of absorption \( R \) by \( l_0 \sim kR \), \( h \) being the centre-of-mass momentum. In the case of the absence of real phase shifts we have

\[ S_{ij} = a, \quad 0 \leq a \leq 1, \quad \text{for} \quad l \leq l_0, \]

\[ S_{ij} = 1, \quad \text{for} \quad l > l_0 \]

(2')

replacing \( r_{ij} \)'s in (1) by the average \( a \).

The case (2) corresponds to the black disk model, and the case (2') to the Table I.

The expressions for the various experimental parameters are given in the limit (2). In the case (2') the expressions for \( I_0, I_P, D \) and \( I_K \) should be multiplied by \((1-a)^2\). The definition of these parameters may be found in reference 2). The \( P_l(\theta) \) are the Legendre polynomials, \( h \) is the centre-of-mass momentum.

<table>
<thead>
<tr>
<th>[np-, p- or p- system]</th>
<th>[pp-system]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l_0 ) [ { \sum_{l=0}^{2l+1} P_l(\theta) }^2 / k^2 ]</td>
<td>[ { \sum_{l=0}^{2l+1} P_l(\theta) }^2 ] [ { \sum_{l=0}^{2l+1} P_l(\theta) }^2 / 2k^2 ]</td>
</tr>
<tr>
<td>( P )</td>
<td>0</td>
</tr>
<tr>
<td>( D )</td>
<td>1</td>
</tr>
<tr>
<td>( R )</td>
<td>( \cos \theta/2 )</td>
</tr>
<tr>
<td>( A )</td>
<td>( -\sin \theta/2 )</td>
</tr>
<tr>
<td>( C_{KP} )</td>
<td>0</td>
</tr>
<tr>
<td>( C_{mn} )</td>
<td>0</td>
</tr>
<tr>
<td>( R' )</td>
<td>( \sin \theta/2 )</td>
</tr>
<tr>
<td>( A' )</td>
<td>( \cos \theta/2 )</td>
</tr>
<tr>
<td>( K_{mn} )</td>
<td>0</td>
</tr>
<tr>
<td>( K_{n,n\ell,nP} )</td>
<td>0</td>
</tr>
<tr>
<td>( K_{n,n\ell} )</td>
<td>0</td>
</tr>
<tr>
<td>( K_{n,n\ell} )</td>
<td>0</td>
</tr>
<tr>
<td>( C_{mn} )</td>
<td>0</td>
</tr>
<tr>
<td>( C_{n,n\ell,n\ell} )</td>
<td>0</td>
</tr>
<tr>
<td>( C_{n,n\ell,n\ell} )</td>
<td>0</td>
</tr>
<tr>
<td>( C_{n,n\ell,n\ell} )</td>
<td>0</td>
</tr>
</tbody>
</table>
the gray disk model.

With the usual procedure\(^a\) we obtain the expressions of angular distribution for the various experimental parameters in the limit (2) or (2'). They are summarized in Table I\(^b\) for two-nucleon system. The same results follow for any two-particle system with spins (1/2, 1/2).

We see that polarization \(P(\theta)\) and spin-correlation parameters \(C_{KP}(\theta), C_{nKP}(\theta), C_{nnKP}(\theta), C_{nnK}(\theta)\) vanish for both \(pp\) and \(np\)-systems. This result comes from the fact that these quantities contain a factor \(\sum_{lj} A_{lj} r_{lj} \sin \left(\frac{\theta_R}{2}\right)_{lj}\) in the expression. Thus the observation of nonvanishing \(P(\theta), C_{KP}(\theta), \ldots\), can indicate the presence of real phase shifts. The absence of \(P(\theta)\) in the limit (2) or (2') has been pointed out also by Lapidus.\(^4\)

The observed values of maximum polarization are

\[
P_{\text{max}} = 42.4 \pm 2.9\% \quad \text{at} \quad 635 \text{ Mev},
38.6 \pm 4.3\% \quad \text{at} \quad 970 \text{ Mev},
30 \pm 9 \% \quad \text{at} \quad 1.7 \text{ Gev}
\]

for \(pp\) scattering.\(^5\) This clearly shows the inapplicability of the optical model calculations even in the several Gev region.

---

\(^a\) In this table the expressions for the normal polarization components \((P, D, C_{nn} \text{ and } K_{nn})\) and cross section \((l_0)\) remain valid also in the relativistic case.
Other polarization parameters are nonvanishing for the \( pp \)-system. Figures 1–3 show the angular distribution of cross section \( I_0(\theta) \), depolarization \( D(\theta) \) and normal component of spin correlation \( C_{nm}(\theta) \), respectively, for the \( pp \)-system. In particular we have

\[
D(90^\circ) = 0, \quad C_{nm}(90^\circ) = -1 \quad (3)
\]

in the limit (2) or (2').

Finally we may summarize the discussion as follows.

i) For \( np-, \tilde{p}p-, \) or \( \tilde{n}n \)-system, all experimental parameters except \( I_0(\theta) \) can serve as good quantities for knowing real phase shifts.

ii) For \( pp \)-system, only \( P(\theta), C_{K\bar{p}}(\theta), C_{nK\bar{p}}(\theta), C_{\pi\pi\pi\pi}(\theta) \) and \( C_{nK\bar{n}}(\theta) \) are insensitive to the diffraction effect.

iii) The large values of polarization measured at energies from 635 Mev to 1.7 Gev indicate that it is possible to get knowledge of nuclear forces at very small distance from the analysis of polarization experiments.

§ 3. An approach to two-baryon interactions in the inner region

We wish here to briefly describe a phenomenological approach to two-baryon interactions at very small distance. Since \( S \) wave can give information on interactions in the innermost region, it is first of all required to analyze scattering experiments in terms of partial waves and to obtain \( S \) wave phase shifts.

In the present situation with difficulties mentioned in § 1, we will consider two-nucleon system, and proceed as follows.

i) We estimate the imaginary parts of the phase shifts from the analysis of data on pion production. At energies from 400 to 900 Mev, it may reasonably be determined with the help of a resonance model for pion production.

ii) Since a reasonable phase shift solution is now known over the entire energy region where elastic scattering is dominant (i.e. below 400 Mev), we start from the neighboring energy region (i.e. 500–700 Mev). By extrapolating this solution we can restrict the region in which real phase shifts are to be searched.

An example of the analysis will be given for 660 Mev \( p-p \) scattering in a separate paper.\(^5\)
N. Hoshizaki and S. Machida

References