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Vector Polarization in Reactions with Spin-1 Particles^{*}

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Vector Polarization in Reactions with Spin-1 Particles

In a recent Letter¹⁾ it was shown that in nuclear or particle reactions involving a spin-1 particle, a determination of the amplitudes can be made without measuring any polarization observables that require vector polarizations in either the initial or final state. Only Lorentz invariance of the reaction was assumed in this discussion. It was noted, however, that discrete ambiguities are not necessarily eliminated. When parity conservation is also imposed, which is the situation of the greatest practical importance, the remaining discrete ambiguities can in fact be easily seen, so we consider it important to expand on and clarify this point.

As before, we consider first the simplest master reaction with the spin structure $0 + 0 \rightarrow 0 + 1$. Parity conservation, with the product of the intrinsic parities $\pi_T = +1$, reduces the three helicity amplitudes A, B, and C (corresponding to helicities +1, 0, -1) to $A=C$ and $B=0$; so the cross section alone, $\sigma = 2|A|^2$, provides the determination of A, and all polarization components are fixed and known.²⁾ For $\pi_T = -1$, $A=-C$ and $B \neq 0$, and the non-zero observables are

$$\sigma = 2|A|^2 + |B|^2 \quad (1)$$

$$\sigma P_{ZZ} = 2|A|^2 - 2|B|^2 \quad (2)$$

$$\sigma(P_{XX} - P_{YY}) = -6|A|^2 \quad (3)$$

$$\sigma P_{XZ} = 3\sqrt{2} \operatorname{Re} AB^* \quad (4)$$

$$\sigma P_Y = 2\sqrt{2} \operatorname{Im} AB^* \quad (5)$$

One sees here that information on the imaginary part of the product of amplitudes is now attainable only from measurement of the vector polarization. Thus, from the tensor polarizations one can determine A , B , and $\cos \phi$, where ϕ is the phase angle between A and B . Since the sign of ϕ is not determined, there is a two-fold discrete ambiguity in the sign of the vector polarization p_y . This can be eliminated, however, by a very crude measurement, since $|p_y|$ is known.

Since the ranges of values of the polarization components in this master reaction are so restricted by parity conservation²⁾, it is useful to examine a reaction with the simplest spin structure for which parity conservation does not limit the ranges of the observables. This occurs for elastic scattering with the spin structure $1 + 0 \rightarrow 1 + 0$, where parity conservation and time-reversal invariance reduce the $3 \times 3 = 9$ transition-matrix amplitudes to four invariant ones, A , B , C , and D . As a generalization of eq. (5), the imaginary parts of the six bilinear products of these amplitudes can be written in terms of the observables as follows³⁾:

$$\begin{aligned}
 \text{Im } AB^* &= -\sigma K \tilde{y}^y \\
 \text{Im } AC^* &= \sigma K \tilde{y}^z \\
 \text{Im } AD^* &= (1/2)\sigma(A_y - K \tilde{y}^x) \\
 \text{Im } BC^* &= -\sigma K \tilde{y}^z \\
 \text{Im } BD^* &= \sigma K \tilde{y}^z \\
 \text{Im } CD^* &= (1/2)\sigma(A_y + K \tilde{y}^x),
 \end{aligned}
 \tag{6}$$

where K_i^{jk} and A_y are polarization transfer coefficients and the vector analyzing-power, respectively. The subscripts (superscripts) refer to the initial (final)-state polarization components. In analogy with eq. (5), it is seen that eqs. (6) involve initial-state vector polarization components, which must be used in order to remove the implied many-fold discrete sign ambiguity. However, it has been shown recently that determinations of, for example, $\text{Re}AB^*$, $\text{Re}BC^*$, $\text{Re}CD^*$, (which involve only tensor polarizations) and $\text{Im}AD^*$ alone can eliminate these discrete ambiguities⁴⁾. Since the determination of $\text{Im}AD^*$ requires only initial-state vector polarization, which is easily provided in a polarized beam, it follows that a complete determination of the amplitudes can be made from measurements of final-state tensor-polarization components alone.

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