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4.1 Exploration of Dynamics through Polarization Experiments

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We present here an overview of our applications of the polarization structure of nuclear and particle reactions to the exploration of the dynamics of those reactions. The results obtained so far would suggest a wider utilization of the techniques used in these applications.

Our first step was to construct a class of formalisms to describe the reaction matrix and the experimental quantities in such a way that the relationship between the bilinear products of reaction amplitudes and the experimental quantities is as simple as possible. This class of formalisms is designated the optimal formalism. In it the matrix relating the bilinear products to the experimental quantities contains all zeroes except for small submatrices along the main diagonal of the matrix[1]. These submatrices are either 1-by-1, or 2-by-2, or 4-by-4, or 8-by-8, but never larger that that for any reaction with four particles of arbitrary spins. When symmetries other than Lorentz invariance are also imposed on the reaction matrix, the matrix further simplifies[2].

If the reaction matrix is written as

$$M = \sum_i a_i \mathcal{S}_i \tag{1}$$

where the a_i's are the reaction amplitudes (functions of the rank-zero tensors composed of the kinematic variables; for example they may be energy and reaction angle), and the $\mathcal{S}_i$'s are the spin tensors; and if we write the experimental observables as

$$L(\mathcal{S}_I, \mathcal{S}_F) \equiv \mathrm{Tr}\,(M\mathcal{S}_I M^+ \mathcal{S}_F) = \sum_i \sum_j a_i a_j^* \mathrm{Tr}(\mathcal{S}_i \mathcal{S}_I^+ \mathcal{S}_j \mathcal{S}_F) \tag{2}$$

where $\mathcal{S}_I$ is a spin tensor describing the initial state of the experiment and $\mathcal{S}_F$ the final state, then in the optimal formalism we choose the $\mathcal{S}_i$'s to have only one non-zero matrix element for each of the $\mathcal{S}_i$'s, and we choose the $\mathcal{S}_{I,F}$'s so that each of them has either only one non-zero diagonal element or two non-zero off-diagonal elements arranged symmetrically around the main diagonal.

The labeling of the rows and columns of the above matrices is by the combination of the spin projection of the initial and final particles, respectively. The quantization directions of these particles, however, can be chosen arbitrarily, thus giving us a multiply infinite class of formalisms, all of which are equally simple in terms of our original criteria. Which of them is the more suitable depends on the particular purpose of the investigation and on the dynamics of the reaction. Thus the selection of the appropriate optimal formalism serves as a powerful tool toward the exploration of dynamics.

When additional symmetries are imposed, the range of choice of optimal formalisms is reduced, but even in the most constrained case in which parity conservation, time reversal invariance, and identical particle constraints all hold (e.g. p-p elastic scattering), we still retain an infinite set of optimal formalisms: One formalism in which the quantization directions are all perpendicular to the reaction plane (transversity formalism) and an infinite set in which the quantization directions are all <u>in</u> the reaction plane but correlated. A special case of the latter is the helicity formalism. Two other of these "planar" formalisms have turned out to be of interest (see below): The one in which the quantization directions are in the plane but perpendicular to the helicity direction (the "planar transverse" frame), and a so-called "magic" frame in which the quantization directions are given by a certain formula dependent on kinematic parameters (used in one-particle-exchange tests)."

The analysis of polarization experiments through the optimal formalism can be used for many purposes: Testing symmetry laws, phenomenologically determining amplitudes, designing new polarization experiments, testing theoretical models, searching for clues for unknown dynamics, etc. In this presentation we will be concerned only with the last two of these.

In testing theoretical mechanisms and models, we devised a test for one-particle-exchange mechanisms[3,4]. This test uses only two general properties of such mechanisms: Factorization, and the definite angular momentum and parity of the exchanged object. Applying this to t-channel exchanges, we found to our surprise that the existing data at 6 GeV/c on p-p elastic scattering indicate strongly the dominance by one-particle-exchanges where the exchanged particle has natural parity. We also applied this test to direct-channel resonances and found that in p-p scattering there is no evidence for a singlet state dibaryon resonance but there is room for a $^3F_3$ resonance though the data do not demand it unambiguously[5]. Incidentally, if we interpret the t-channel one-particle-exchange dominance mentioned above in p-p elastic scattering at 6 GeV/c in terms of the quark-level language, the conclusion points at the dominance of one-gluon exchange (that is, an exchange process in which one gluon carries most of the momentum transfer with one or possibly more other gluons present only to take care of color)[6].

More specific models were tested also. The data for p-p elastic scattering at 6 GeV/c were used to test a recent and sophisticated version of the Regge-pole model. It was found that apart from qualitative agreement in magnitude of the largest of the five reaction amplitudes, the model and the phenomenologically determined amplitudes show no resemblence.[7]

We also investigated the question of how one can determine off-shell amplitudes from the polarization quantities of a larger reaction in which the off-shell process is embedded and showed the specifically model-dependent nature of this situation[8].

Our work to look for clues of dynamics in situations in which the dynamics is presently unknown has focused on p-p elastic scattering and on pion photoproduction, since complete or almost complete sets of data are available there.

For p-p scattering we found that in a broad range of energies (from 500 to 6000 MeV) the five reaction amplitudes are, at the entire range of reaction angles, either pure real or pure imaginary if we work in the planar transverse optimal frame[9,10]. We are now searching for a dynamics that would yield this; the existing models do not give it. We found a similarly marked situation in pion photoproduction between 1 and 3 GeV and the entire measured angular range, where two phase differences of the four amplitudes are equal[11]. Here also we have been unable so far to find any existing model that would yield such a relationship.

We also applied our approach to higher energy p-p scattering (in the 1-30 GeV range) and constructed a model which predicts the polarization observables observed so far and makes predictions for others[12]. We also demonstrated that in general ther is no reason to expect that polarization effects be small at high energies[13,14]. Finally we also discussed polarization aspects of pion-nucleon scattering at high energies and its connection with QCD[15].

There are a large number of additional situations in nuclear, intermediate energy, and high energy physics awaiting the application of these methods.

References

1) G. R. Goldstein and M. J. Moravcsik, Ann. Phys. (N. Y.) 98 (1976), 128.
2) G. R. Goldstein and M. J. Moravcsik, Ann. Phys. (N.Y.) 142 (1982), 219.
3) G. R. Goldstein and M. J. Moravcsik, Phys. Rev. D30 (1984), 55.
4) G. R. Goldstein et al, Phys. Lett. 152B (1985), 263.
5) G. R. Goldstein, M. J. Moravcsik, and F. Arash, J. of Phys. G (in press) (1985).
6) G. R. Goldstein and M. J. Moravcsik, Z f. Phys. (in press) (1985).
7) M. J. Moravcsik, N. Ghahramany, and G. R. Goldstein, Phys. Rev. D30 (1984), 1899.
8) H. W. Fearing, G. R. Goldstein, and M. J. Moravcsik, Phys. Rev. D29 (1984), 2612.
9) N. Ghahramany, G. R. Goldstein, M. J. Moravcsik, Phys. Rev. D28 (1983), 1086.
10) M. J. Moravcsik, F. Arash, and G. R. Goldstein, Phys. Rev. D31 (1985), 2360.
11) G. R. Goldstein and M. J. Moravcsik, Nouv. Cim. 73A (1983), 196.
12) F. Arash et al, Phys. Rev. Rap. Comm. D31 (1985) 667.
13) M. J. Moravcsik and F. Arash, Phys. Rev. D (in press) (1985).
14) G. R. Goldstein and M. J. Moravcsik, Phys. Lett. B (in press) (1985).
15) G. R. Goldstein and M. J. Moravcsik, Pion-Nucleon Scattering and QCD Dynamics, (submitted for publication, April 1985).