Phase Shifts for Nucleon-Nucleon Scattering at 280 Mev*

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(Received September 7, 1954)

RECENT results on the polarization of nucleons as measured by double scattering have given more specific indications regarding phase shifts[1] than have been previously available. In particular, the more recent data[2] at 280 Mev indicate[3] the presence of phase shifts for orbital angular momenta $L>1$ at this energy. A closer examination shows that even more specific conclusions can be drawn.

If the analysis of $(P\boldsymbol{\sigma})_{p-p}$ is confined to orbital angular momenta $L<4$, it may be shown that even if one assumes the presence of coupling between $^3P_2$ and $^3F_2$, the terms in $\sin\theta\cos\varphi\cos^5\theta$ can be present only if there is a $^3F_4$ phase shift $\delta_4{}^F$. The presence of terms of above type in $(P\boldsymbol{\sigma})_{p-p}$ indicates, therefore, that there are effects caused by F-wave phase shifts δ^F originating directly rather than through coupling to states of lower orbital angular momenta. The conclusion regarding the presence of direct δ^F effects rests heavily on the presence of the term $0.116(\sin 6\theta)$ mb/sterad in the analysis of $(P\boldsymbol{\sigma})_{p-p}$. According to the authors,[2] the presence of this term is not quite certain since the data can be represented reasonably well without it. Considering the Fourier analysis of the experimental curve by means of Fourier's formula, the coefficient 0.116 is a sum of two positive integrals in the intervals from $(0°,30°)$ and $(60°,90°)$ and one negative integral over $(30°,60°)$. Each of the positive integrals is ~ 3 times the sum of the three so that the accuracy of the result is rather poor. The most uncertain of the three is the integral over $(0°,30°)$. The knowledge of the curve in this region would admit an error of 10 percent in the integral over it corresponding to an error of perhaps 30 percent in the number 0.116. A qualitatively incorrect value of this coefficient thus appears unlikely but is not altogether excluded since both for $p-p$ and $p-n$ the experimental points at $\theta\cong 18°$ are systematically off the curves. If the data could be made more accurate in this respect, clarification regarding F waves would result.

Since there is little doubt regarding the presence of noncentral forces at low energies, as indicated by the quadrupole moment of the deuteron, it appears likely that there are differences between different δ^D and between different δ^F. The coupling of $^3S_1$ to $^3D_1$ is very likely for the same reason. Calculation shows that if $\delta_2{}^D=\delta_3{}^D=0$ and if all phase shifts but δ^D, δ^S are neglected then $(P\boldsymbol{\sigma})_{p-n}$ contains no term in $\sin\theta\cos\theta P_2 \times(\cos\theta)$ the only dependence being on $\sin\theta\cos\theta$. While it is probable that the differences in the δ^D and the coupling of $^3S_1$ to $^3D_1$ are connected through the interaction energy, one can separate phenomenologically the coupling from the direct occurrence of $\delta_2{}^D$ and $\delta_3{}^D$. In this sense the $^3D_1$ state caused by $^3S_1$ does not produce $\sin\theta\cos\theta P_2(\cos\theta)$ terms, without the aid of cross products involving the pairs S-G, D-D, P-F, etc., the sum of the L's in a product being even if an odd power of $\cos\theta$ multiplying the factor $\sin\theta$ is desired.

Among the D-D combinations the $^3D_1-{}^3D_2$ term does not occur with $\sin\theta\cos^3\theta$ similarly to the absence of $^3F_3-{}^3F_2$ combinations with $\sin\theta\cos^5\theta$. Presence of coupling between $^3D_1$ and $^3S_1$ or between $^3F_2$ and $^3P_2$ does not interfere with this rule. The conclusion regarding the role of $^3S_1-{}^3D_1$ coupling differs only in emphasis from that of Fried, the possibility of $^3D_2={}^3D_3=0$ in the presence of the coupling being specifically considered here.

The ^3F phase shifts required by the data are of the order of 15°, an amount sufficiently smaller than the ^3P phase shifts to make it conceivable that phase shifts for $L>3$ are not important in the analysis of $p-p$ data at this energy. The repulsive character of potentials expected for triplets with odd L in $p-p$ scattering on the symmetric theory may be expected to contribute to the smallness of these phase shifts.

* Assisted by the Office of Ordnance Research, U. S. Army.
1 A. Garren, Phys. Rev. **92**, 213 (1953); de Carvalho, Heiberg, Marshall, and Marshall, Phys. Rev. **94**, 1796 (1954).
2 Chamberlain, Donaldson, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **95**, 850 (1954).
3 B. D. Fried, Phys. Rev. **95**, 851 (1954). In the paper by Thaler, Bengston, and Breit, Phys. Rev. **94**, 683 (1954) quoted by Fried, Eq. (9) contains a misprint, < appearing for >, in contradiction to the text immediately to the right of Eq. (9).

Polarization of High-Energy Protons in Elastic Scattering on Helium and Carbon*

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(Received September 14, 1954)

WE have previously reported[1] results of experiments concerning polarization of proton beams by scattering from complex nuclei. Other authors[2] have also dealt with this problem. Particular interest has been attached to polarization by elastic scattering and several publications[3-5] have treated the theory for this case.

As previously, we have attempted to isolate elastic scattering by insertion of an absorber into the counter telescope used to detect the scattered protons. Owing to range straggling in the absorber and to inhomogeneity of the beam, it is impossible to exclude with certainty all protons resulting from inelastic scattering. For example, we mention the scattering by carbon in which the lowest excited state is at 4.4 Mev, while our counting arrangement could be guaranteed to reject scatter-