Phase Shifts for Nucleon-Nucleon Scattering at 280 Mev*

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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.

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[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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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 scattering events only if at least 20 Mev were lost to the scattering nucleus.

At small angles of scattering from any target the elastic scattering is easily determined simply because it is strongly predominant over inelastic scattering. However, at angles larger than about 20° the so-called elastic scattering is contaminated with an appreciable fraction of protons from inelastic scattering.

Helium is of special interest in this regard because there are no excited or unbound states at energies lower than 20 Mev. Therefore, our existing method of detection is adequate to exclude all protons inelastically scattered by helium at any angle.

We have measured the elastic-scattering cross sections of helium for 315-Mev 74 percent-polarized protons, and of carbon for 290-Mev 64 percent-polarized protons. Our second targets were 1.7 g/cm^2 of liquid helium and 3.2 g/cm^2 of graphite respectively. The polarized beams were obtained by scattering 340-Mev protons to the left at 15° and 18° respectively, from a beryllium first target inside the cyclotron as previously described.[1] The beam polarizations were determined in separate experiments by external scattering from beryllium at 15° and 18°.

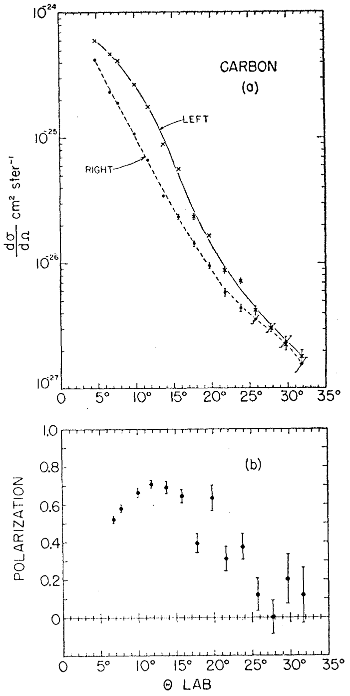

FIG. 2(a). Differential-scattering cross sections *versus* left and right scattering angles for 64 percent-polarized 290-Mev protons scattered elastically by carbon. (b) Polarization $P(\Theta)$ of protons elastically scattered by carbon *versus* scattering angle. At angles greater than 20° the so-called elastic scattering from carbon is contaminated by inclusion of some inelastically scattered protons.

The results for both left and right scattering from helium are shown in Fig. 1(a), in which the differential-scattering cross sections have been corrected for nuclear attenuation in the absorber. Figure 1(b) shows the polarization $P(\Theta)$ in the elastic scattering by helium as computed from the points shown in Fig. 1(a) and the known beam polarization. The relation used is

$$e(\Theta)=P_BP(\Theta) \tag{1}$$

in which

$$e(\Theta)=[\sigma_{\text{left}}(\Theta)-\sigma_{\text{right}}(\Theta)]/[\sigma_{\text{left}}(\Theta)+\sigma_{\text{right}}(\Theta)],$$

P_B is the polarization of the beam, and $P(\Theta)$ is the polarization that would be produced by scattering an unpolarized beam at angle Θ on the substance in question (in the present experiment, helium or carbon). Figure 2 shows the corresponding results for a carbon second target.

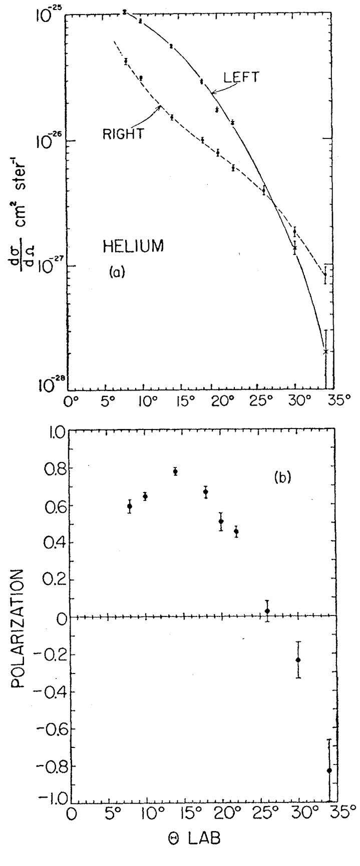

FIG. 1(a). Differential-scattering cross sections *versus* left and right scattering angles for 74 percent-polarized 315-Mev protons scattered elastically by helium. (b) Polarization $P(\Theta)$ of protons elastically scattered by helium *versus* scattering angle.

An interesting feature of the helium results is that they show a definite change in sign of the polarization. Changes in sign near minima of the diffraction scattering curve of carbon have been predicted by Fermi, by Malenka, and by Snow, Sternheimer, and Yang.[3] However, it is not clear that the observed change in sign should be attributed to the mechanism implied by these theoretical considerations. On the other hand Tamor[5] assumed the validity of the impulse approximation for light nuclei, and on that basis predicted that the polarization of carbon and helium should be the same. That they are the same seems fairly well borne out for angles small enough (up to 20°) that the carbon experiment can be deemed to represent purely elastic scattering. In the framework of Tamor's theory either helium or carbon polarization data should be viewed as exemplifications of that part of the nucleon-nucleon scattering that involves no change in spin state of the target nucleons.

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Energetic Disintegration of a Heavy Nuclear Fragment*

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SEVERAL events[1–11] have been observed in photographic emulsion where a nuclear fragment stopped and subsequently disintegrated. In some of these events a π meson was emitted, while in other events, only nuclear particles were observed. The energy release from the disintegration of the nuclear fragment has been measured quite accurately in a few cases[6,7,9] and found to be consistent with the assumption that a Λ^0 particle was loosely bound in the nuclear fragment.

An energetic disintegration of a nuclear fragment was found in a 1000-micron glass-backed plate which had been exposed to cosmic rays in a sky-hook balloon flight. A photograph of the event is shown in Fig. 1. The primary star is of the type $(22+9p)$. The track of the nuclear fragment F, is 192 microns long. The thindown along the track F and the multiple scattering near the end of the track show that the fragment stopped before producing the secondary star. From a comparison of the thindown characteristics along track F with other tracks of known Z, the charge of the fragment is found to be greater than $2e$ and definitely less than $5e$. The secondary star has four prongs. The characteristics of the tracks from the secondary star are given in Table I.

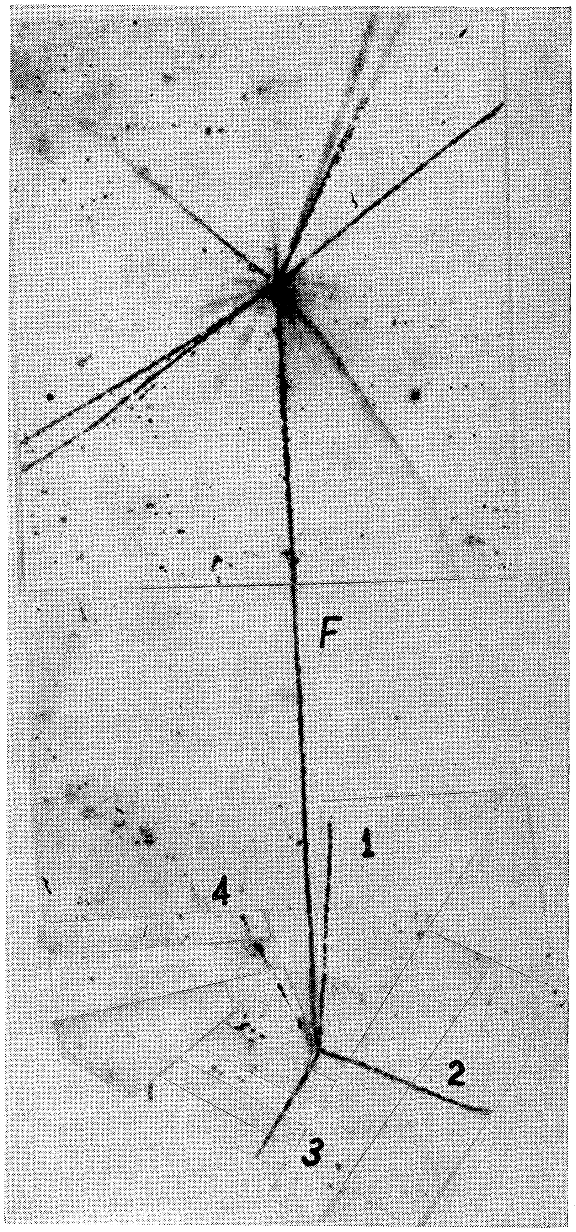

Fig. 1. A nuclear fragment F from a cosmic-ray star stops in the emulsion and produces a secondary star which has four prongs. Tracks 1 and 3 were produced by a proton or deuteron or triton; and track 2 by an α particle. Track 4 is most likely due to a negative π meson. (Observer: J. Slowey.)

If track 4 is assumed to be a π meson, the residual momentum of the charged particles from the secondary star is 342 Mev/c; if track 4 is assumed to be a proton, the residual momentum is 680 Mev/c. If the residual momentum is carried away by two neutrons traveling together in the direction to conserve the residual momentum, the energy of the two neutrons is found to be 28 Mev if track 4 is assumed to be a π meson, and 116 Mev if track 4 is assumed to be a proton. If track 4 is ascribed to a π meson, the minimum energy release from the secondary star is $2.7+14+20+(45-18)+28 \cong 92$ Mev. If track 4 is due to a proton, the minimum