where θ_γ is the angle between $\vec{k}_0$ and $\vec{k}_\gamma$, and Δn_γ is the difference in indices of refraction for ω_0 and ω_γ taken positive for normal dispersion. Hence θ_γ can be real in isotropic media only if anomalous dispersion is present or for a nondispersive medium. From such media, or from anisotropic crystals, or from material of finite extent, it would appear possible to couple out infrared radiation at frequency ω_γ.

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†On leave of absence from Comitato Nazionale per l'Energia Nucleare, Laboratori Nazionali del Sincrotrone, Frascati, Italy.

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ANALYSIS OF PROTON-ALPHA SCATTERING

C. C. Giamati
National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio

and

V. A. Madsen* and R. M. Thaler*
National Aeronautics and Space Administration, Lewis Research Center
and Case Institute of Technology, Cleveland, Ohio
(Received 24 June 1963)

The earliest information regarding the spin-orbit interaction in nuclear scattering came from analysis of proton-alpha scattering. The low-energy scattering data were analyzed by Critchfield and Dodder[1] and Dodder and Gammel.[2] From these analyses, low-energy polarization was predicted and experimentally confirmed. The low-energy phase shifts were extrapolated to about 40 MeV by Gammel and Thaler[3] through further analysis of sketchy experimental data. The GT phase shifts were compatible with an optical-model potential with exchange.

The polarization predicted in GT has been confirmed at energies below about 20 MeV. Recent measurements of proton-alpha polarization by Hwang, Nordby, Suwa, and Williams[4] at 38.3 MeV are in qualitative disagreement with these predictions, as shown in Fig. 1, and hence necessitate a re-examination of the problem.

The new polarization data allow construction of a revised contour plot of polarization versus energy and angle similar to Fig. 7 of GT. Such a polarization map based on experimental data[5] alone is shown in Fig. 2. Measurements now in progress may be expected to fill in the details in the region between 20 and 40 MeV.

Since there now exist very detailed elastic-scattering data at 39.8 MeV[6] and equally detailed polarization data at very nearly the same energy, a complete phase-shift analysis is possible. We have so analyzed the polarization and elastic-scattering data by using the GT phase shifts as a starting point. The phase shifts obtained as well as the GT phase shifts are listed in Table I. The fit to the polarization data is shown in Fig. 1. We note that, although the predicted polarizations are very different, the two sets of phase shifts do not greatly differ.

In the course of this analysis, it was found that no fit was possible unless angular momentum states with $l \leq 4$ were included. We also found that the fit was not improved by al-

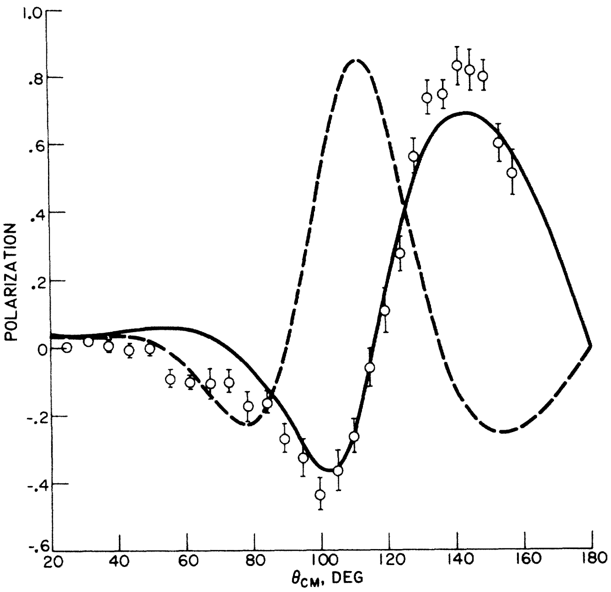

FIG. 1. Polarization in elastic proton-alpha scattering at 38.3 MeV versus angle. The experimental points shown are due to Hwang et al. The dashed curve is the GT prediction. The solid curve results from the present phase-shift analysis.

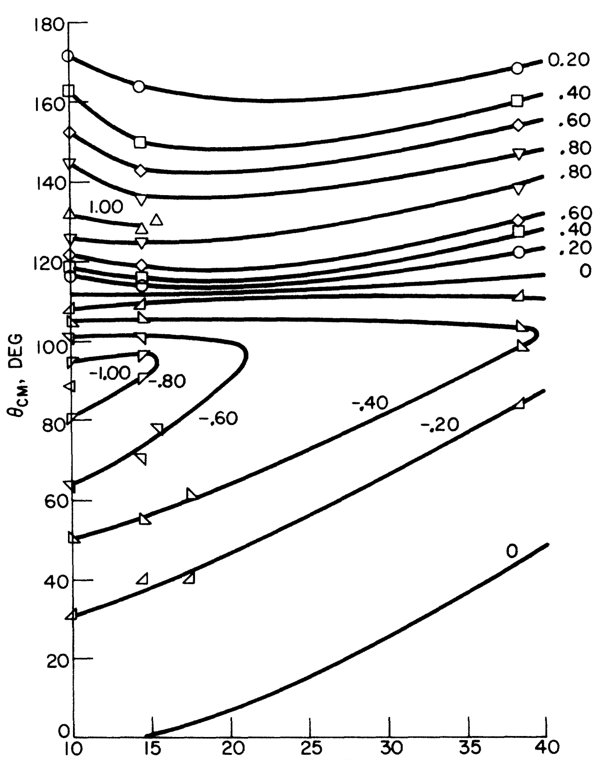

FIG. 2. Contour map of polarization against energy and angle. The contours are labeled by the polarization.

Table I. Phase shifts for proton-alpha elastic scattering at 38.3 MeV. The symbols $\delta_l^{(+)}$ and $\delta_l^{(-)}$ are defined as the phase shifts for $J = l + \frac{1}{2}$ and $J = l - \frac{1}{2}$, respectively. The quantities f_l and g_l are defined in Eqs. (1) and (2). The quantities in parentheses are the GT values.

l	$\delta_l^{(+)}$	$\delta_l^{(-)}$	f_l	g_l
0	0.987 (0.987)	...	0.987 (0.987)	...
1	1.144 (1.172)	0.572 (0.662)	0.953 (1.002)	0.191 (0.170)
2	0.432 (0.469)	0.156 (0.260)	0.322 (0.385)	0.055 (0.042)
3	0.233 (0.222)	0.115 (0.040)	0.182 (0.144)	0.017 (0.026)
4	0.075 (0.050)	0.001 (0.026)	0.042 (0.039)	0.008 (0.002)

lowing the phase shifts to be complex. There is no assurance that the phase shifts shown in Table I represent a unique solution to the data, since we have only examined a portion of phase-shift space in the GT region. However, we believe this to be the significant region because of its relation to the lower energy data.

To comprehend better the qualitative meaning of the phase shifts in Table I, the auxiliary quantities f_l and g_l were constructed, which are defined as

$$f_l = \frac{(l+1)\delta_{J=l+\frac{1}{2},l} + l\delta_{J=l-\frac{1}{2},l}}{2l+1} \tag{1}$$

and

$$g_l = \frac{\delta_{J=l+\frac{1}{2},l} - \delta_{J=l-\frac{1}{2},l}}{2l+1}. \tag{2}$$

To first order in δ, these are the quantities that enter the spin-independent and spin-dependent parts of the scattering amplitude. The quantities f_l and g_l are shown in Table I.

In Fig. 3, f_l is plotted versus l. A curve drawn through the points at integral l would wiggle rather strongly, whereas similar quantities calculated from local "optical-model potentials" do not give rise to such "wiggles." We take this to be an indication of the exchange character of the nucleon-alpha interaction.[7]

Consider an optical-model potential with exchange whose spin-independent part is of the

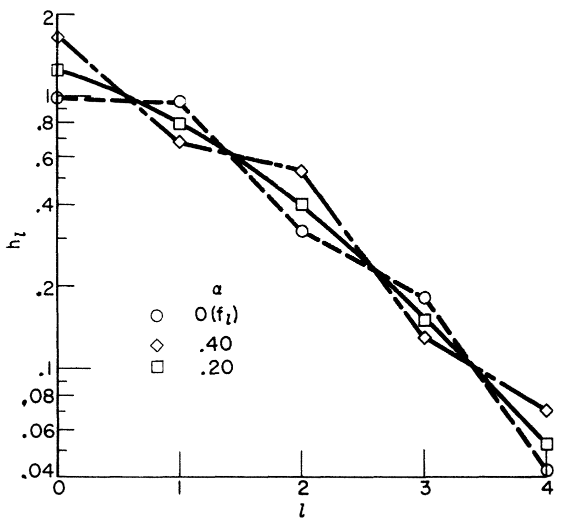

FIG. 3. The quantity $h_l(\alpha) \equiv [(l+1)\delta_l^{(+)} + l\delta_l^{(-)}]/(2l+1)[1-(-1)^l\alpha]$ versus l at 38.3 MeV. The circles represent the values for $\alpha = 0$, which corresponds to the f_l in Eq. (1); the diamonds represent the values for $\alpha = 0.40$; and the squares represent the values for $\alpha = 0.20$.

form

$$V_0(r)[1-\alpha P_x], \tag{3}$$

where P_x is the space-exchange operator. In a linear approximation,

$$f_l \approx \Delta_l[1-(-1)^l\alpha], \tag{4}$$

where Δ_l is the phase shift due to the potential $V_0(r)$. In order to estimate Δ_l,

$$h_l(\alpha) \equiv f_l/[1-(-1)^l\alpha] \tag{5}$$

may be plotted for various values of α. If a unique value of α is found that yields a smooth curve for $\Delta_l(\alpha)$ against l, we may identify this value of α with the parameter α of Eq. (3). From Fig. 3, we obtain $\alpha \approx 0.20 \pm 0.05$. Furthermore, the behavior of $\Delta_l = h_l(\alpha = 0.20)$ as a function of l is very similar to the l dependence of the same quantity calculated from a local optical model.

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OBSERVATION OF THE PRODUCTION OF A $\overline{\Xi}^0$ PARTICLE*

C. Baltay, J. Sandweiss,† and H. D. Taft
Yale University, New Haven, Connecticut

and

B. B. Culwick, W. B. Fowler, J. K. Kopp, R. I. Louttit, J. R. Sanford, R. P. Shutt, D. L. Stonehill, R. Stump, A. M. Thorndike, and M. S. Webster
Brookhaven National Laboratory, Upton, New York

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For the known stable and quasi-stable particles, only one antiparticle, the $\overline{\Xi}^0$, had not been observed so far,[1] although its existence was anticipated. We wish to report here an example of $\overline{\Xi}^0$ production in the reaction

$$\bar{p} + p \rightarrow \Xi^- + \overline{\Xi}^0 + \pi^+, \tag{1}$$

with subsequent observed decays $\Xi^- \rightarrow \Lambda + \pi^-$, $\Lambda \rightarrow p + \pi^-$, and $\overline{\Xi}^0 \rightarrow \overline{\Lambda} + \pi^0$ (vertex unseen), $\overline{\Lambda} \rightarrow \bar{p} + \pi^+$. The antiprotons ($\bar{p}$) were produced by the Brookhaven AGS, separated at 3.69 BeV/c, and observed in a 20-in. long liquid hydrogen bubble chamber. Observation of $\Xi^- + \overline{\Xi}^+$ production was reported previously.[2,3] Observation of the reaction $\bar{p} + p \rightarrow \Xi^0 + \overline{\Xi}^0$, while possible in principle, is less likely than observation of Reaction (1) because the neutral Ξ-decay vertices are both unseen.