energy level available to charged carriers originated from excess magnesium and no levels were from excess oxygen. (b) Excess magnesium could move through the lattice comparatively easily so that impurity levels disappeared by heating samples at high temperatures. This conclusion was also reached from the fact that heat treatment destroyed the coloration due to excess magnesium in the visible region. (c) Furthermore, by taking account of Day's results,[4] it was deduced that the charge carriers due to excess magnesium levels were holes, the positive sign of the thermoelectric power obtained by Mansfield[2] being thus explained. These results are not understood by a simple electronic structure model. However, a definite model cannot be established yet.

A full report will be given in the *Journal of the Physical Society of Japan.*

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Experiments on Nucleon-Nucleon Scattering with 312-Mev Polarized Protons

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IN a previous paper[1] we reported our results on *p-p* scattering using polarized protons. In the framework of our general program of studying nucleon-nucleon scattering, we would have liked to investigate *n-p* scattering with polarized neutrons; however, we are still unable to obtain highly polarized neutrons and the next best possibility is to bombard deuterons with highly polarized protons.[2]

Neglecting in first approximation the binding of the deuteron, the processes that occur in *p-d* bombardment are *p-p* and *p-n* scattering in which a *p-p* or an *n-p* pair escapes at approximately 90° in the laboratory system. In addition to this there is elastic scattering of the protons. These processes are schematically represented in Fig. 1.

We have detected and measured processes (a) and (b) by coincidence techniques and we have also counted single neutrons and single protons.

In Figs. 2 and 3 we show the asymmetrical part of the cross section, $P\sigma$:

$$P\sigma=\tfrac{1}{2}[\sigma(\theta,0)-\sigma(\theta,\pi)], \tag{1}$$

where $\sigma(\theta,\varphi)$ is the differential cross section for a completely polarized beam scattering on an unpolarized target. The incident protons travel in the z direction and

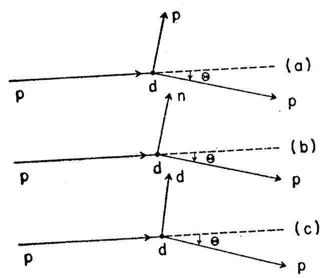

FIG. 1. Processes occurring in *p-d* scattering.

are polarized along the y axis. The quantity $P\sigma$ is computed from the relation

$$P\sigma=e\sigma_{\text{unpolarized}}/P', \tag{2}$$

where P' is the polarization of the incident beam used. The deuterium scattering experiment yields e; $P'=0.73$ is obtained from measurements of the asymmetry when the scattering is elastic and targets A and B are

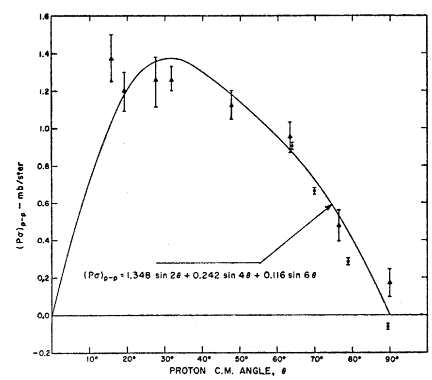

FIG. 2. $P\sigma$ in *p-p* scattering as a function of θ. Triangles are from reference 1 (290 Mev); dots are from this experiment (312 Mev).

identical; for *p-p* scattering $\sigma_{\text{unpolarized}}$ is assumed to be 3.75 mb/sterad,[3] and for *n-p* scattering it is taken from previous work.[4]

Figure 2 refers to the asymmetric part of the *p-p* scattering with some points taken from previously reported data[1] using a hydrogen target, and some

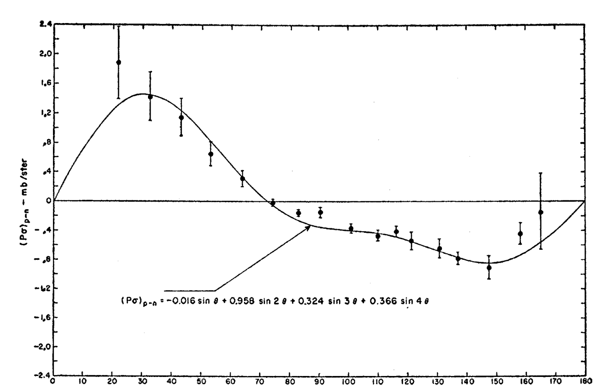

FIG. 3. $P\sigma$ for *n-p* scattering from *d-p* scattering measurements, as a function of θ. Energy of incident protons is 312 Mev.

points from p-p coincidence counting with a deuterium target [process (a)]. Figure 3 refers to process (b), with data obtained partly by p-n coincidence counting and partly by counting neutrons alone, all from a deuterium target. Data on process (c), as well as the experimental description of the work and a detailed discussion, are to be given later.

The curves thus obtained give some information on nucleon-nucleon scattering. A first step in their analysis is to obtain from them whatever information is possible on phase shifts of the different partial waves.

By Fourier analysis of the asymmetric part of the cross section limited to the minimum number of harmonics necessary to fit the data, we find

$$(P\sigma)_{p-p}=1.348\sin2\theta+0.242\sin4\theta+0.116\sin6\theta, \quad (3)$$

$$(P\sigma)_{n-p}=-0.016\sin\theta+0.958\sin2\theta+0.324\sin3\theta+0.366\sin4\theta. \quad (4)$$

The solid curves in Figs. 2 and 3 represent these equations. If the sixth harmonic term is omitted from Eq. (3) the fit is still fairly good; however, the fourth harmonic term is necessary in both Eqs. (3) and (4) to fit the data satisfactorily.

From the Fourier analysis it is possible to infer some conclusions on the phase shifts, as is to be shown in the following letter by Dr. B. D. Fried.

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Phase Shifts for High-Energy Nucleon-Nucleon Scattering

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SEVERAL attempts have recently been made to fit nucleon-nucleon scattering data using a small number of phase shifts.[1] In particular, Thaler and Bengston have shown that with seven phase shifts—^1S, ^3S, ^1P, ^3P and a single ^3D—it is possible to get a good fit to both the p-p and n-p differential cross sections at an energy of 260 Mev. It is of interest to see whether the recent experiments by Chamberlain *et al.*[2] on the scattering of polarized protons at a similar energy are consistent with the Thaler and Bengston phase shifts.

If partial waves with $L>2$ are excluded and Coulomb effects are neglected, then, for an incident beam of completely polarized protons,

$$(d\sigma/d\Omega)_{p-p}=k^{-2}[A_0P_0(\cos\theta)+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)+B_1\cos\phi\sin\theta P_1(\cos\theta)], \quad (1)$$

where k is the wave number of the relative motion, θ and ϕ are the usual center-of-mass polar angles, and the initial momentum and polarization of the incident protons have been chosen along the z and y axes, respectively. Explicit expressions for A_0, A_2, and A_4 in terms of phase shifts are given by Thaler, Bengston, and Breit.[3] In the same notation,

$$B_1=9S(\delta_{11},\delta_{12})+6S(\delta_{10},\delta_{12}), \quad (2)$$

where $S(x,y)=-S(y,x)=\sin x\sin y\sin(x-y)$, and δ_{1J} are the ^3P phase shifts.

In their analysis, Thaler and Bengston assumed that (a) the nuclear interaction is charge-independent; (b) the triplet phase shifts are all equal,

$$\delta_{21}=\delta_{22}=\delta_{23}\equiv{}^3K_2; \quad (3)$$

(c) the mixing of ^3S and ^3D waves, such as would result from a tensor force or other noncentral interaction, can be neglected. The cross section for polarized protons scattered by neutrons is then

$$(d\sigma/d\Omega)_{p-n}=\tfrac{1}{4}(d\sigma/d\Omega)_{p-p}+\tfrac{1}{4}k^{-2}\left\{\sum_{n=0}^{4}C_nP_n(\cos\theta)+\cos\phi\sin\theta[D_0P_0(\cos\theta)+D_2P_2(\cos\theta)]\right\}. \quad (4)$$

Again, the C_n are given by TBB,[3] while

$$D_0=5S(^3K_0,\delta_{12})-3S(^3K_0,\delta_{11})-2S(^3K_0,\delta_{10}),$$
and
$$D_2=5[5S(^3K_2,\delta_{12})-3S(^3K_2,\delta_{11})-2S(^3K_2,\delta_{10})], \quad (5)$$

where $^3K_0$ is the ^3S phase shift.

An examination of the qualitative features of Eqs. (1) and (4) shows that they are incompatible with the data on the scattering of polarized protons as presented in Figs. 2 and 3 of the preceding letter. The following points may be made: (1°) According to Fig. 3, $(P\sigma)_{p-n}$ contains an appreciable amount of fourth harmonic, whereas Eq. (4) allows none; (2°) The amplitudes of the second harmonic components of $(P\sigma)_{p-p}$ and $(P\sigma)_{p-n}$ have a ratio of 1.4 instead of the ratio of 4.00 predicted by Eqs. (1) and (4); (3°) The $(P\sigma)_{p-p}$ data cannot be fitted with a second harmonic term alone.

One obvious conclusion which may be drawn from these observations is that partial waves with $L>2$ are necessary, as is certainly to be expected at this energy ($k^{-1}=5.1\times10^{-14}$ cm). In particular, since only triplet partial waves can contribute to the polarization, the fourth harmonic in $(P\sigma)_{p-p}$ requires at least a ^3F term. However, it may be noted that the discrepancies (1°) and (2°) above could be resolved without using partial waves with $L>2$. The absence of a second harmonic term in $(P\sigma)_{p-n}-\tfrac{1}{4}(P\sigma)_{p-p}$ and the lack of a fourth