the mass values given by Mattuch *et al.*,[15] the rest mass energy difference between the $N^{14}+\alpha$ system and F^{18} ground state was calculated to be 4.432 Mev.

The excitation energies and total widths given by Heydenburg and Temmer[16] were obtained from $N^{14}(\alpha,\alpha)N^{14}$ and $N^{14}(\alpha,p)O^{17}$ differential cross-section measurements. Their measurements were made from 6.0- to 7.1-Mev excitation. They were not successful in analyzing the data. The resonant energies and widths listed were obtained from a qualitative inspection of the $N^{14}(\alpha,p)O^{17}$ data. A third resonance at 7.1-Mev (excitation) which they inferred from their data was not found in this investigation.

The resonant energies and total widths given by Ahnlund[11] were obtained from the $O^{17}(p,\alpha)N^{14}$ reaction. No analysis of her data has been reported. The resonant energies were determined by observing the bombarding energy corresponding to the peak α-particle yield. A systematic energy difference could occur between Ahnlund's values and the others since the comparison involves the rest mass energy difference between the $N^{14}+\alpha$ and $O^{17}+p$ systems.

Note added in proof.—Angular momentum and parity assignments for levels in the same energy region of F^{18} have recently been reported [J. R. Risser, private communication, July, 1958] to the author. For a discussion of these assignments, see Kashy, Miller, and Risser, Phys. Rev. **112**, 547 (1958).

ACKNOWLEDGMENTS

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Polarization of Protons from $C^{12}(d,p)C^{13}$ Reaction with Deuterons of 1060 kev

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The polarization of protons from the $C^{12}(d,p)C^{13}$ reaction has been measured for a deuteron energy of 1060 kev at angles 20° and 140°. Elastic scattering by carbon was used to analyze the polarization. Nuclear emulsions were used as the proton detector. The observed magnitude of the polarization was found to be $P=54.3\pm9.5\%$ at 20° and $P=29.4\pm12.6\%$ at 140°. Positive sign of the polarization corresponds to the vector product $\mathbf{K}_p\times\mathbf{K}_d$.

I. INTRODUCTION

SINCE the value and the sign of the polarization of particles emitted in a reaction are much more sensitive to the nuclear parameters than the angular distribution, the measurement of this polarization can be a useful tool for obtaining more detailed information about the mechanism of the reaction.

The comparison of experimentally obtained results of the polarization for the reaction produced by deuterons[1,2] with the refined Butler's theory[3–6] shows that the sign of the observed polarization is in agreement with some theories[5,6] but that its magnitude is greater than any theoretically predicted.

In this experiment the polarization of protons from the $C^{12}(d,p)C^{13}$ reaction has been measured at a forward and a backward angle. The elastic scattering of protons by carbon was used as the analyzing reaction. The energy of the incident deuteron beam was lower than the Coulomb barrier for the target nucleus and the bombarding energy used in this experiment does not correspond to a resonance in the excitation curve.

II. PRINCIPLE OF THE METHOD

As a measure of this polarization $P_1(\theta_1)$, an asymmetry in the intensities of scattered protons at the same angles ($\pm\theta_2$) to the left and the right in the plane perpendicular to P_1 in the second reaction has been taken. If this asymmetry is expressed as $e=(L-R)/(L+R)$, where L and R are the number of scattered protons at equal angles to the left and the right, then $P_1(\theta_1)P_2(\theta_2)=e(\theta_1,\theta_2)$, where $P_2(\theta_2)$ is the polarization of the protons elastically scattered by carbon.

The carbon nucleus is similar to the helium, the standard analyzer; it is a spin-zero nucleus and the protons scattered on it show an anomaly[7,8] in the

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region of 1.75 Mev. This anomaly is the result of two virtual levels, a $(j=3/2-)$ level, and a $(j=5/2+)$ level of an unstable N^{13} nucleus. A resonant scattering which originates from the existence of such an anomaly ought to give a strong spin-orbit interaction. Using the data of the phase-shift analysis[8,9] deduced from the experimental $C^{12}(p,p)C^{12}$ differential cross section, we have calculated the polarization of protons scattered by carbon according to the equation

$$P(\theta_2,E)=\frac{AB^*+A^*B}{|A|^2+|B|^2},$$

where

$$A(\theta_2)=-\tfrac{1}{2}\alpha\frac{1}{k}\csc^2(\theta_2/2)\exp[i\alpha\ln\csc^2(\theta_2/2)]+\frac{1}{k}\sum_{l=0}^{\infty}[(l+1)\exp(i\delta_l^+)\sin\delta_l^+ + l\exp(i\delta_l^-)\sin\delta_l^-]e^{2i\alpha_l}P_l(\cos\theta_2);$$

$$B(\theta_2)=\frac{i}{k}\frac{d}{d\theta_2}\sum_{l=1}^{\infty}[\exp(i\delta_l^+)\sin\delta_l^+ - \exp(i\delta_l^-)\sin\delta_l^-]e^{2i\alpha_l}P_l(\cos\theta_2).$$

Variation of the polarization with energy and angle in the center-of-mass system is shown on Fig. 1. Diatlov and Rosenzweig[10] also suggested carbon as an analyzer for polarization of protons elastically scattered on carbon in the energy region from 1.2 to 2.4 Mev. This polarization has been experimentally verified.[11]

The polarization is considered to be positive when it lies in the direction of the vector product $\mathbf{K}_p'\times\mathbf{K}_p$, where $\mathbf{K}_p'$ and $\mathbf{K}_p$ are the outgoing and incoming proton wave vectors, respectively.

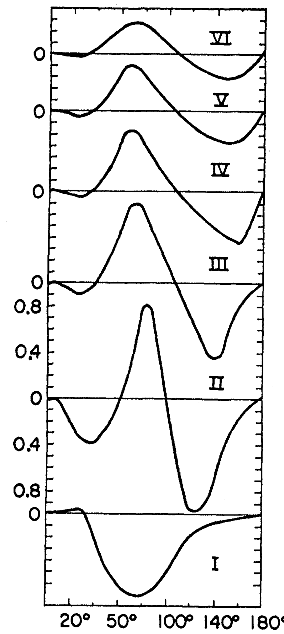

FIG. 1. Polarization produced in proton-carbon scattering as a function of angles (c.m. system) for various incident proton energies E_p in Mev in lab system: I=1.60 Mev; II =1.75 Mev; III=1.80 Mev; IV=1.85 Mev; V=1.90 Mev, and VI=2.00 Mev. (In the abscissa, 50° should read 60°.)

III. EXPERIMENTAL PROCEDURE

A diagram of the experimental arrangement is shown in Fig. 2. A well-collimated beam of 1-Mev deuterons from the Cockcroft-Walton generator hit the first target (T_1) which is placed in the center of a large evacuated chamber. Around this target were placed two small chambers which could be rotated, allowing the observation of the emerging protons at any angle with respect to the deuteron beam. These small chambers contain the secondary targets (T_2) as well as the photographic emulsions. The emulsions were placed at angles ranging from 10° to 170° with respect to the proton beam emanating from the first target. Both targets were made by burning benzene. The first target was supported by a nickel foil and the secondary targets by thin Formvar foil, of thickness between 0.3 and 0.7 milligrams/cm². The entire experimental apparatus as well as the beam tube was surrounded by lead and paraffin.

The protons produced in the first reaction passed through nickel foil windows and into the secondary chambers. These windows stopped elastically scattered deuterons and decreased the proton energy to less than 2 Mev which is the region in which the polarization in proton-carbon scattering is greatest. This second scattering occurred at an energy of 1.75 Mev. The second scattered protons were observed at six angles on each side. The exposures for all of these angles were made simultaneously for an initial bombardment of 14 microampere hours. The entire apparatus was aligned for each exposure. The proton detectors were 50 μ Ilford E-1 emulsions with extra plasticizer added.

As the nuclear emulsions were found to contain a lot of knockon protons tracks caused by neutrons, it was necessary to perform the background exposure. This background run was carried out on the same conditions as the main exposure, except that the nuclear plates were screened against the scattered protons by nickel foil.

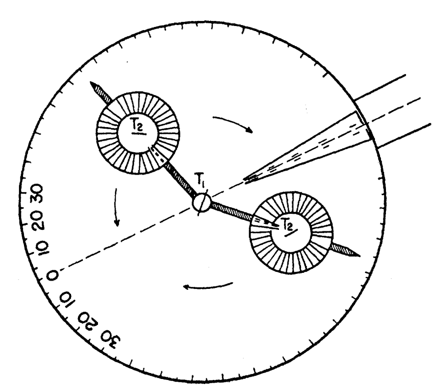

FIG. 2. Scheme of the experimental arrangement.

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[11] P. V. Sorokin and A. Taranov, Doklady Akad. Nauk S.S.S.R. **111**, 82 (1956) [translation: Soviet Phys. Doklady **1**, 637 (1956)].

TABLE I. Background correction.

θ_2 (c.m.)	$\theta_1=20°$ R	L	$\theta_1=140°$ R	L
44° 42′	31	28	12	11
55° 17′	22	22	6	7
65° 44′	18	18	6	7
76° 2′	10	8	6	6
86° 45′	5	5	6	6
96° 19′	5	5	5	5

The protons were scanned in swaths corresponding to an angular width of about 1° in the second scattering. The following criteria were used: The tracks had to start on the surface of the emulsions, be oriented in the direction toward the scattering center, have the correct length, and have an azimuthal angle between +9° and −9°. In order to minimize any subjectiveness of individual scanners many of the plates were scanned by several observers.

As in this experiment the symmetry of the whole apparatus is the most important, an experimental verification was made. Two identical experiments were carried out under completely the same conditions, first in the ordinary way, second with the chambers turned round for 180°, so that left and right were interchanged. The observed results were the same in both cases, which showed that there was no evident error from a mechanical asymmetry in the chamber.

IV. RESULTS AND DISCUSSION

The intensities of elastically scattered protons by carbon to the left and the right for angles in the center-of-mass (c.m.) system $\theta_2=44° 42'$, $55° 17'$, $65° 44'$, $76° 2'$, $86° 45'$, $96° 19'$, with respect to the incoming protons, have been measured. From the observed data, taking into consideration the background correction (Table I), the ratio $e(\theta_1,\theta_2)=(L-R)/(L+R)$ has been estimated. These magnitudes were then divided by the values of $P_2(\theta_2)$ for given angles, which correspond to the polarization produced in proton-carbon scattering at 1.75 Mev. Polarization $P_2(\theta_2)$ (Fig. 1, curve II) is negative up to 60° and positive over 60°. The polarization of protons from $C^{12}(d,p)C^{13}$, $P_1(\theta_1)=e(\theta_1,\theta_2)/P_2(\theta_2)$, must be the same for all θ_2 angles.

In Table II the data are summarized. At each θ_1 angle two measurements were made with the chamber in the normal position and one measurement with the chamber in the inverted position. At the larger angles the yield was smaller and, therefore, a larger surface of the plates was scanned. The average of sixteen measurements yields for the polarization of the protons $P_1=54.3\pm9.5\%$ at $\theta_1=20°$ and $P_1=29.4\pm12.5\%$ at $\theta_1=140°$.

TABLE II. Summary of data.

θ_2(c.m.)	$\theta_1=20°$ R	L	e	P_1(%)	$\theta_1=140°$ R	L	e	P_1(%)
44° 42′	895	636	−0.174	54.1	183	153	−0.764	23.5
55° 17′	681	568	−0.095	52.5	187	168	−0.058	32.3
65° 44′	276	307	0.057	56.6	141	150	0.028	28.3
76° 2′	243	494	0.356	58.4	188	285	0.210	34.5
86° 45′	149	280	0.312	41.0	146	208	0.143	23.8
96° 19′	48	57	0.099	60.6	97	107	0.053	32.6
44° 42′	186	134	−0.171	53.0	460	384	−0.090	28.1
55° 17′	169	140	−0.104	57.4	400	360	−0.055	30.3
65° 44′	163	182	0.062	61.4	362	385	0.031	30.8
76° 2′	502	884	0.310	50.1	88	127	0.196	32.1
86° 45′	172	398	0.408	53.6	77	112	0.202	26.6
Inverted chamber								
44° 42′	174	125	−0.178	55.4	127	106	−0.104	32.5
55° 17′	326	270	−0.104	57.5	195	177	−0.047	26.2
76° 2′	70	116	0.284	46.6	160	230	0.187	30.7
86° 45′	84	201	0.432	56.7	141	202	0.202	24.5
96° 19′	125	148	0.089	54.4	254	280	0.050	30.6

The bombarding energy of 1060 kev is lower than the Coulomb barrier for the (d,p) reaction and, therefore, Coulomb effects are present as well as possible stripping effects. For this reason the angular distribution of the protons has a peak in the backward as well as the forward direction, the backward peak being comparable and perhaps greater than the forward peak.[12,13] The polarization of the protons at 20° is large and the sign is positive in the direction of $\mathbf{K}_p\times\mathbf{K}_d$, corresponding to $j_n=1\text{-}\frac{1}{2}$. This value corresponds to a value obtained earlier for the same reaction but a higher deuteron energy. The polarization in the backward direction is considerably smaller than the polarization in the forward direction but of the same sign. The theoretical significance of the polarization in the backward direction has, to the best of the authors' knowledge, not as yet been discussed.

Further work on these subjects is in progress.

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