Polarization of the Gamma Rays in the $F^{19}(p,\alpha\gamma)O^{16}$ Reaction*

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The polarizations of the 6.13-, 6.9-, and 7.1-Mev gamma rays from the $F^{19}(p,\alpha)O^{16*}(\gamma)O^{16}$, $E_p=0.87$ Mev, reaction have been observed using the photodisintegration of the deuteron to detect polarization. Range measurements on the photoprotons separated the 6.13-Mev gamma ray from the other two, which were only slightly resolved. Knowing the relative intensities of the 6.9- and 7.1-Mev gamma rays and their unresolved angular distribution coefficient, it is possible, nevertheless, to deduce the separate polarizations from the observed total polarization. Polarization ratios, $I(0°)/I(90°)$, of 0.9 ± 0.1, 1.9 ± 0.3, and 0.4 ± 0.3 were obtained for the 6.13-, 6.9-, and 7.1-Mev gamma rays, respectively, emitted at 90° to the proton beam. These values are in good agreement with the polarizations expected for the assignment of a 2^- state in Ne^{20} and 3^-, 2^+, and 1^- states in O^{16} as deduced by Seed and French from directional correlation measurements on this reaction.

I. INTRODUCTION

FOLLOWING a suggestion by Madansky, it was shown by Falkoff[1] that parity changes in successive nuclear transitions could be determined from polarization measurements on the emitted gamma rays. Hamilton[2] has given the theory for the case in which the polarization of one gamma ray is measured relative to the direction of emission of a second gamma ray in a cascade process. Experiments of this type have been performed by Metzger and Deutsch.[3] The theory can be readily applied to a process in which a material particle replaces the gamma ray whose polarization is not determined. An alpha-gamma correlation of this type has been measured by French and Newton[4] in the reaction, $F^{19}(p,\alpha)O^{16*}(\gamma)O^{6}$, $E_p=0.34$-Mev, $E_\gamma=6.13$ Mev.

The theory can also be extended to the case of a gamma ray and a bombarding particle in a nuclear reaction. In such an experiment it is not necessary to detect radiations in coincidence, since the entering particles are unidirectional. In this case nuclear plates can be used as the detectors of the radiation and its polarization. In the experiments mentioned above, scintillation counters were employed and the Compton effect provided the polarization sensitive mechanism. For gamma-ray energies above about 4 Mev, however, it would seem desirable to use the photodisintegration of the deuteron as the polarization sensitive reaction. In the energy range of the present work, 6 to 7 Mev, this reaction proceeds chiefly by photoelectric disintegration. The yield of photoprotons is, to a good approximation, proportional to $\cos^2\alpha$, where α is the angle between the direction of the photoproton and the direction of polarization of the gamma ray.[5] With a favorable experimental arrangement, therefore, a very large polarization effect can be achieved for a completely polarized gamma ray, as has been recently demonstrated by Wilkinson[6] in observing the distribution of photoprotons produced by the gamma ray in the $H^2(p,\gamma)He^3$ reaction. The Compton scattering in the same energy range produces only about a 20 percent effect for a perfectly polarized gamma ray in a practical experimental arrangement.

The aim of the present work was to detect the polarizations of the 6.13-, 6.9-, and 7.1-Mev gamma rays relative to the proton in the $F^{19}(p,\alpha)O^{16*}(\gamma)O^{16}$, $E_p=0.874$-Mev, reaction.[7] The detection was accomplished by observing the photoprotons in the $D(\gamma,p)n$ process in nuclear emulsions impregnated with D_2O.[6,8] A complete measurement of the polarization correlation would consist in determining the intensity and the polarization of the gamma rays as a function of the correlation angle. Since Sanders[9] has obtained the intensity distribution of the gamma rays, it was in fact only necessary to establish the polarization of the radiation emitted at 90°, at which angle there is a maximum effect. Recently, the proton-alpha and alpha-gamma directional correlations at this resonance have been measured by Seed and French,[10] so that a very complete description of the reaction has now been obtained.

II. EXPERIMENTAL METHOD

Thin fluorine targets were prepared by exposing various metals to bromine trifluoride gas. Tantalum fluoride targets were generally suitable, but with beams of high-intensity water-cooled copper fluoride targets were employed. Four separate runs were made. The first two (~100 μa-hr) were obtained with the statitron in the Physics Department at Johns Hopkins University. The last two runs (~250 μa-hr) were made with the statitron at the Department of Terrestrial

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1 D. L. Falkoff, Phys. Rev. **73**, 518 (1948).
2 D. R. Hamilton, Phys. Rev. **74**, 782 (1948).
3 F. Metzger and M. Deutsch, Phys. Rev. **78**, 551 (1950).
4 A. P. French and J. O. Newton, Phys. Rev. **85**, 1041 (1952).
5 H. A. Bethe and R. F. Bacher, Revs. Modern Phys. **8**, 122 (1936).
6 D. H. Wilkinson, Phil. Mag. **43**, 659 (1952).
7 An earlier report on this experiment is given by L. W. Fagg and S. S. Hanna, Phys. Rev. **88**, 1205 (1952).
8 G. Goldhaber, Phys. Rev. **81**, 930 (1951).
9 J. E. Sanders, Phil. Mag. **43**, 630 (1952).
10 J. Seed and A. P. French, Phys. Rev. **88**, 1007 (1952).

Magnetism of the Carnegie Institute of Washington. The standard practice for each run was to expose two plates impregnated with D_2O and one control plate with H_2O.

The target chamber was an aluminum cylinder, $9\frac{1}{2}$ in. long, $2\frac{1}{2}$ in. in diameter, with a $\frac{1}{16}$-in. wall. The target made an angle of 45° with the beam and with the planes of the nuclear emulsions. The latter were placed outside the chamber, normal to the radiation emitted at 90°. The emulsions, soaked in D_2O or H_2O, were held in water tight cassettes made of stainless steel and mounted on copper bars which were maintained at the low temperature at which the plates were soaked. The temperature control was necessary to avoid spoiling the emulsion and to prevent changes in emulsion thickness.

Four hundred micron Ilford C-2 emulsions were soaked in D_2O (or H_2O) until saturated, at a fixed temperature between 10°C and 16°C. Saturation was desirable to obtain maximum photoproton intensity and to insure uniform water density throughout the emulsion. The resulting decrease in grain density of the tracks did not seriously impair range measurements. The shrinkage factor (ratio of thickness during exposure to thickness after development) of each emulsion was measured by means of a micrometer. Although, for the most part, track depths were not measured, a depth criterion was used, and knowledge of the shrinkage factor was necessary in order to interpret the results. The shrinkage factor varied from about 6 to 9, the value depending mostly on the temperature at which the plates were soaked. The emulsions were developed using the "dry development" procedure prescribed by Dainton *et al.*[11] with a few modifications. The use of amidol bisulfite as a developer was effective in preventing stain in the developed emulsions.

With the targets used, there were very few gamma rays, other than those from O^{16*}, which could produce photoprotons from the photodisintegration of the deuteron. Protons from all other origins could be detected in the H_2O control plates. Possible sources of background were (γ,p) reactions on other nuclei in the emulsion, or (p,n) reactions in the target emitting neutrons which would produce recoil protons in the emulsion. The threshold energies for both types of reactions, however, are above the proton and gamma energies of this experiment. In fact virtually the only background observed was that accumulated in the emulsion before a run was made.

The plates were scanned with a Leitz binocular microscope using a magnification of 900, 450, or 250. The center of the scanning area, usually circular, was located at the point at which gamma rays emitted at 90° to the beam were normal to the emulsion plane. For each acceptable track the projected range and direction in the emulsion plane were measured. When using the 900 magnification the depth of a track was also recorded.

[11] Dainton, Gottiker, and Lock, Phil. Mag. **42**, 596 (1951).

The criteria for acceptance of a track were as follows. (1) The track must not be scattered through an angle greater than 10° as seen in the emulsion plane. This limit was extended to 20° when the sense (direction) of the track could be determined. (2) The track must lie entirely in the emulsion. (3) The track must be in "sharp" focus along its entire length. (4) The track must not have an observed length indefinite by more than 2.5 microns. The third criterion was not used with the 900 magnification, since depths were measured.

Actually the high magnification was used only on one plate of the first run. It was then found that the third criterion could be successfully applied and the labor greatly reduced. Furthermore, the energy discrimination based on projected range and the third criterion was found to be as good as that based on actual range which involved a depth measurement.

II. ANALYSIS OF THE MEASUREMENTS

If the photodisintegration is electric dipole in nature, the angular distribution of photoprotons is given by:

$$I(\alpha)d\Omega = I_0 \cos^2\alpha d\Omega, \tag{1}$$

where α is the angle between the proton direction and the polarization direction of the gamma ray. If a polar axis is established along the propagation direction of the gamma ray, Eq. (1) in polar coordinates becomes:

$$I(\theta,\phi)d\theta d\phi = I_0 \sin^3\theta \cos^2\phi d\theta d\phi. \tag{2}$$

The complement of θ is the dip angle of the photoproton in the emulsion. ϕ is the azimuthal angle measured experimentally. If R is the range of the photoproton, its projection on the emulsion plane is $p = R\sin\theta$; hence

$$I(p,\phi)dpd\phi = I_0 R^{-3} p^3 (R^2 - p^2)^{-\frac{1}{2}} \cos^2\phi dpd\phi. \tag{3}$$

Then

$$I(p)dp = \int_0^{2\pi} I(p,\phi)d\phi dp = I_0 \pi R^{-3} p^3 (R^2 - p^2)^{-\frac{1}{2}} dp, \tag{4}$$

and

$$I(\phi)d\phi = \int_{p_c}^{R} I(p,\phi)dpd\phi = C_0 \cos^2\phi d\phi, \tag{5}$$

where $C_0 = (I_0/3)R^{-3}(p_c^2 + 2R^2)(R^2 - p_c^2)^{\frac{1}{2}}$.

Equation (4) gives the distribution in projected range p expected from the microscope measurements. A lower limit p_c of the projected range is established by the criterion that the tracks be in sharp focus in the microscope. Its value depends on the depth of focus and the shrinkage factor. A comparison of the theoretical distribution with an experimental distribution is shown in Fig. 3. The quantity p_c for the 6-Mev distribution is shown at 46μ and for the 6.9-Mev distribution it falls at 69μ, well above R for the 6-Mev distribution.

Equation (5) gives the distribution in ϕ expected for a gamma ray polarized along the beam direction, $\phi = 0°$.

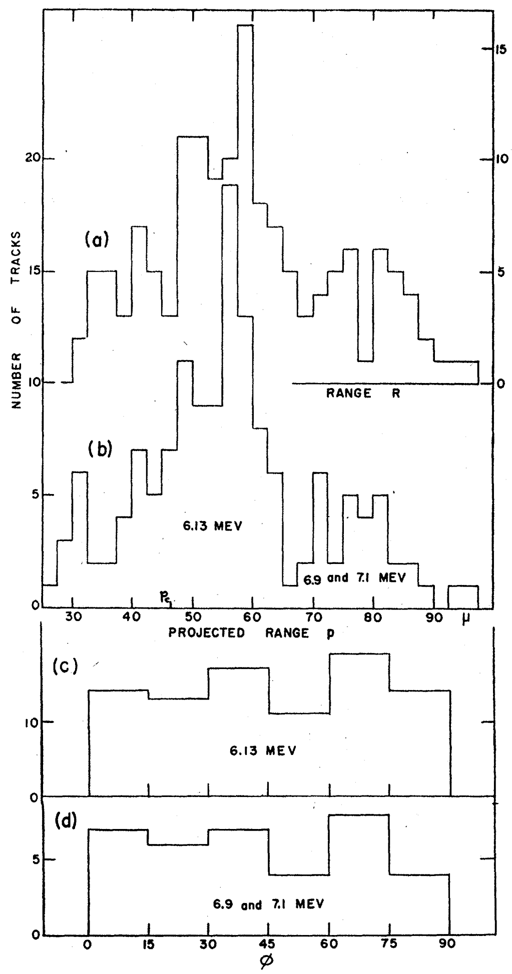

FIG. 1. (a) Actual range distribution of photoprotons from the first run; (b) projected range distribution of photoprotons; (c) polarization distribution for the 6.13-Mev gamma; (d) for the 7-Mev group.

If the gamma ray is partially polarized, it can be treated as two waves with random phases and with mutually perpendicular polarizations, one parallel and the other perpendicular to the proton beam. Adding the distributions corresponding to each component we get a resultant ϕ dependence of the form:

$$I(\phi)=1+B\cos^2\phi, \qquad (6)$$

where $1+B=I(0°)/I(90°)$ is the polarization ratio P.

The effect of the extended scanning area on the polarization ratios measured in the experiment was investigated and found to be negligible. The ratios were, however, corrected for the contribution of the magnetic dipole interaction in the photodisintegration process, as given by theory,[5] but not for the small admixture of quadrupole interaction.

IV. RESULTS

The results from three runs are presented in Figs. 1 to 4. Since it was not possible in many cases to determine the sense of a track, no effort was made to do so, and it was only necessary to use two quadrants in recording the azimuthal angle. Because of the symmetry in the polarization distributions, most of the distributions are shown folded about $\phi=0°$.

The results of the first run are presented in Fig. 1. Since depth measurements were made in this run, it was possible to make a comparison between the distribution achieved by plotting actual range [Fig. 1(a)] and that achieved by plotting projected range [Fig. 1(b)]. Both distributions contain only tracks of dip angle $<35°$. The two groups in Fig. 1 correspond to photoprotons produced by the 6.13-Mev gamma and the unresolved 6.9- and 7.1-Mev gammas. The distributions in ϕ for the 6.13-Mev gamma [Fig. 1(c)] and the 7-Mev group [Fig. 1(d)] were plotted using tracks with projected ranges between 45μ and 62.5μ, and between 65μ and 90μ, respectively.

The short-range tail (below p_c) in the range distribution of the 6.13-Mev gamma ray indicates that background was fairly high in this run, and the polar-

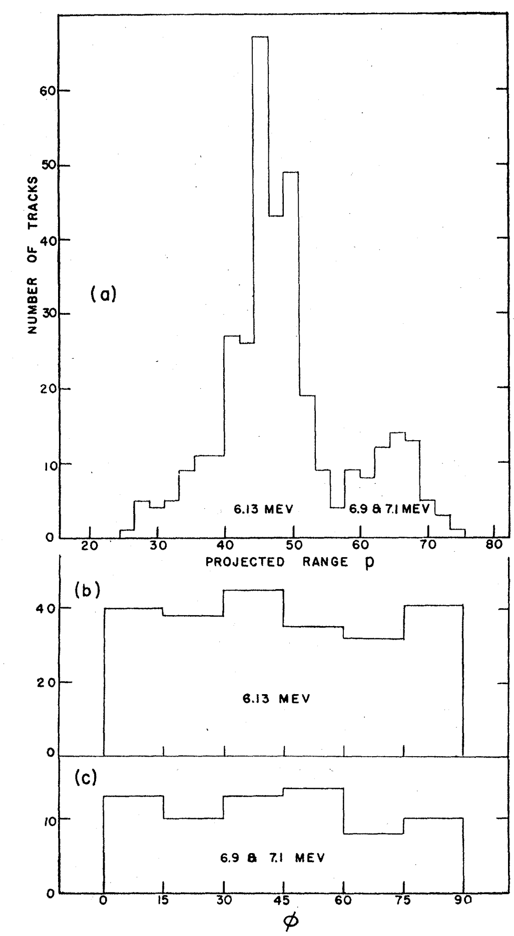

FIG. 2. (a) Projected range distribution from the third run; (b) polarization distribution for the 6.13-Mev gamma; (c) for the 7-Mev group.

ization distributions are not considered entirely reliable, although they do agree with the work of later runs. This background was even more pronounced in the second run, and it is believed that it was due to a previous exposure to fast neutrons which produced recoil protons in the emulsion. Since the (n,p) process has a relatively high cross section, a very low neutron flux would produce a troublesome background.

Because of these background difficulties, the next run was made with freshly eradicated emulsions. The results are presented in Fig. 2. The improvement in the background situation is established by the fact that no acceptable tracks were found in the portion of the H_2O plate that was scanned (about $\frac{1}{12}$ that scanned in the D_2O plates). The improvement is also apparent from Fig. 2(a), where p_c (at 41μ) and R (at 50μ) are well defined for the 6.13-Mev distribution. The polarization distributions in Figs. 2(b) and 2(c) are made up of tracks of projected range, $40\mu<p<53.5\mu$ and $56\mu<p<76\mu$.

To improve statistics and in particular to study the 7-Mev group, a run of greater intensity was obtained. Uneradicated plates which hold more D_2O were used, but stringent background precautions were taken. The background as determined from the H_2O control plate was estimated to be 2 percent. The results of this run are presented in Fig. 3. The arrows at 78μ and 83.5μ give the predicted ranges R for the two unresolved distributions of the 7-Mev group. The ratio of the 6.13-Mev yield to the unresolved 6.9 and 7.1 yield is 2.9 ± 0.4, in good agreement with other investigations.[9]

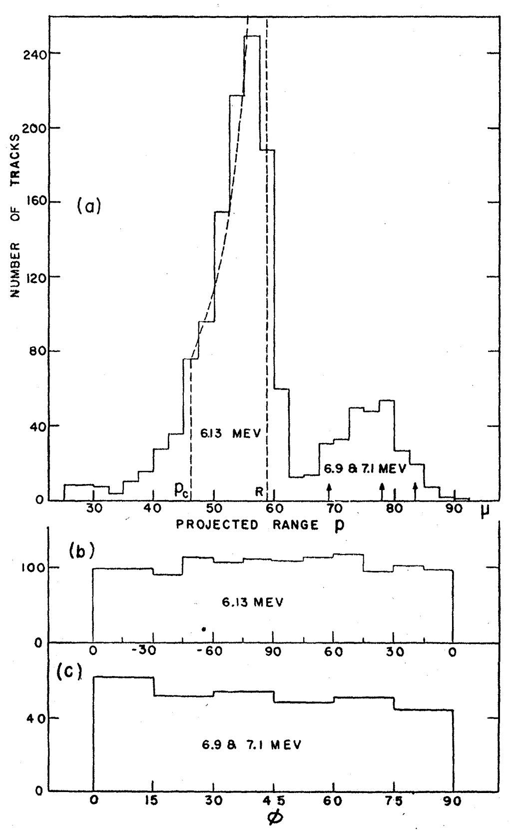

FIG. 3. (a) Projected range distribution from the fourth run; (b) unfolded polarization distribution, 6.13-Mev gamma; (c) folded, 7-Mev group.

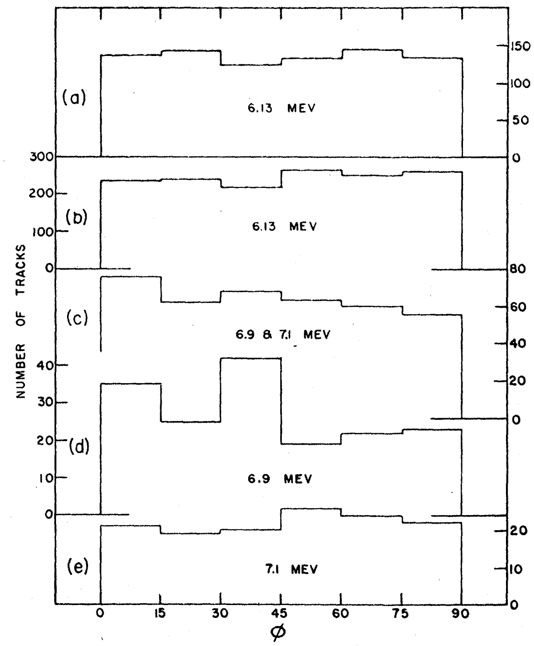

FIG. 4. (a) Total polarization distribution for 6.13-Mev gamma from the third and fourth runs (excepting one plate in the fourth run); (b) total polarization distribution for 6.13-Mev gamma (all plates); (c) for the 7-Mev group; (d) attempted resolution of the distribution for the 6.9-Mev gamma; (e) for the 7.1-Mev gamma.

The polarization distribution for the 6.13-Mev gamma (tracks with $45\mu<p<62.5\mu$) is shown unfolded in Fig. 3(b). The small increase in intensity toward 90° in evidence in this distribution was present only in one of the plates of this run. The other plate, and the other runs gave little evidence of a polarization effect for the 6.13-Mev gamma, and the discrepancy has not yet been adequately explained. Figure 3(c) gives the polarization distribution for the 7-Mev group (tracks with $67.5\mu<p<92.5\mu$), which shows a definite polarization effect.

The combined polarization distributions for the last two runs are plotted in Fig. 4. For the 6.13-Mev distribution in Fig. 4(a), however, data from the plate showing the intensity increase toward 90° are not included. The total 6.13-Mev distribution is shown in Fig. 4(b). Figure 4(c) gives the distribution for the 7-Mev group. Figures 4(d) and 4(e) represent an attempt to resolve the 6.9- and 7.1-Mev distributions by plotting tracks from the extremities of the 7-Mev group. There are noticeable intensity increases in the 6.9-Mev and 7.1-Mev distributions toward 0° and 90°, respectively.

TABLE I. Polarization ratios for radiation emitted at 90° and for an angular distribution of the form $1+A\cos^2\theta$.

Radiation	Parity	$P=I(0°)/I(90°)$
$E1$, $M2$	$-$	$(1-A)/(1+A)$
$M1$, $E2$	$+$	$(1+A)/(1-A)$
$E3$	$-$	$(1+\frac{2}{3}A)/(1-\frac{2}{3}A)$
$M3$	$+$	$(1-\frac{2}{3}A)/(1+\frac{2}{3}A)$

The dipole and quadrupole expressions are given by Hamilton (see reference 2). Expressions for higher poles may be obtained by means of the formulas (for magnetic radiation):

$$I_\theta=4M^2[(2L+1)(L+1)L]^{-1}\sin^{-2}\theta[Y_L^M]^2,$$
$$I_\phi=[(2L+1)(L+1)L]^{-1}\{[(L-M)(L+M+1)]^{\frac{1}{2}}Y_L^{M+1}-[(L+M)(L-M+1)]^{\frac{1}{2}}Y_L^{M-1}\}^2.$$

V. DISCUSSION

Table I gives the polarization ratios for radiation emitted at 90° to the proton beam and for an angular distribution of the form $1+A\cos^2\theta$. A_2 and A_3 will represent the angular distribution coefficients, and P_2 and P_3 the polarization ratios of γ_2 (6.9-Mev) and γ_3 (7.1-Mev), respectively. A_t and P_t will designate these quantities for the unresolved group.

Table II gives all possible assignments of polarization for γ_2 and γ_3 taking into account only the form (dipole or quadrupole) of the polarization ratios and the sign of the coefficients. Taking $A_t=0.33$, as given by Sanders,[9] values of P_t are calculated for each case. It is seen that the value $P_t=1.32\pm0.24$, obtained from a least square analysis of the data in Fig. 4, eliminates all but two of the possibilities. Of these only case 8 in Table II gives $P_2>1$ and $P_3<1$, in qualitative agreement with the polarization trends in Fig. 4. The other choice, case 5, gives just the reverse trends for P_2 and P_3. If one or both of the gamma rays are octupole, the possible values of P_t given in Table II are altered somewhat, but the above conclusion is unchanged. Hence we take $P_2=(1+A_2)/(1-A_2)$, $P_3=(1-A_3)/(1+A_3)$, $A_2>0$, and $A_3>0$, with it understood that the coefficient is multiplied by $\frac{2}{3}$ in the polarization ratio for octupole radiation.

Table III gives the computed angular distribution coefficients and polarizations for those spin and parity assignments to states in Ne^{20} and O^{16} which lead to short-range alpha particles and to distributions of the type $1+A\cos^2\theta$. These coefficients were calculated by the method of Biedenharn, Arfken, and Rose.[12] The lowest possible values of the orbital quantum numbers, l_p and l_α are assumed in each case. The effect of mixed values of l_p and l_α was investigated, but in no case in which the spin of Ne^{20} is 2 or greater is the sign of the coefficient altered by any reasonable admixture of higher l-values.[12] For the 1^+ case, it is necessary to consider $l_p=0$ and 2 in order to obtain non-zero values of A. For any states in O^{16} leading to the correct polarizations, however, opposite signs for A_2 and A_3 are obtained in this case. Among all the possibilities in Table III the only ones in qualitative agreement with $P_2>1$, $P_3<1$, $A_2>0$, and $A_3>0$ are those for which the Ne^{20} state is 2^-, γ_2 is $E2$ or $E3$, and γ_3 is $E1$, $M2$, or $M3$.

Finally, these possibilities are investigated quantitatively in Table IV. Experimental values for A_2 and A_3 were computed using $A_t=0.33$, $P_t=1.32$, and a 3.3:1 ratio for the intensities of γ_2 and γ_3 at 90°. This ratio was obtained from an analysis of the range distribution in Fig. 3. The results are, however, quite insensitive to the precise value of this ratio, but the preponderance of 6.9-Mev radiation makes the computed values of A_3 more uncertain than those for A_2, as indicated by the errors given in the table. It is noticed also that different experimental values for A_2 and A_3 are obtained if one or both of the gamma rays are octupole because of the factor of $\frac{2}{3}$ in the octupole expression for the polarization. The best numerical agreement in Table IV is obtained when γ_2 is $E2$ and γ_3 is $E1$. It is necessary, however, to consider the effect on the coefficients of higher values of l_p and l_α. For a 2^- state in Ne^{20} both $l_p=1$ and 3 are allowed. An investigation of the terms introduced by $l_p=3$ shows that the coefficients of $\cos^4\theta$ and $\cos^2\theta$ are of comparable

TABLE II. Polarization assignments for the 6.9- and 7.1-Mev gamma rays. The only datum used in computing values of P_t is that $A_t=0.33$, which also eliminates the possibility that A_2 and A_3 are both negative.

Case	P_2	A_2	P_3	A_3	P_t
1	$\frac{1+A_2}{1-A_2}$	Any	$\frac{1+A_3}{1-A_3}$	Any	2.0
2	$\frac{1-A_2}{1+A_2}$	Any	$\frac{1-A_3}{1+A_3}$	Any	0.5
3	$\frac{1-A_2}{1+A_2}$	<0	$\frac{1+A_3}{1-A_3}$	>0	>2.0
4	$\frac{1-A_2}{1+A_2}$	>0	$\frac{1+A_3}{1-A_3}$	<0	<0.5
5	$\frac{1-A_2}{1+A_2}$	>0	$\frac{1+A_3}{1-A_3}$	>0	$0.5\rightarrow2.0$
6	$\frac{1+A_2}{1-A_2}$	<0	$\frac{1-A_3}{1+A_3}$	>0	<0.5
7	$\frac{1+A_2}{1-A_2}$	>0	$\frac{1-A_3}{1+A_3}$	<0	>2.0
8	$\frac{1+A_2}{1-A_2}$	>0	$\frac{1-A_3}{1+A_3}$	>0	$0.5\rightarrow2.0$

[12] Biedenharn, Arfken, and Rose, Phys. Rev. **83**, 586 (1951). For 1^+ and 2^- states in Ne^{20} Seed and French (reference 10) have tabulated the correlation functions in a very convenient form for investigating the effect of mixed l values.

magnitude (except of course for $E1$ radiation). To the extent that a term in $\cos^4\theta$ has not been observed in the angular distributions, therefore, contributions from $l_p=3$ may be neglected. For all the cases in Table IV except $E1$, two or more values of l_α are allowed. In each case, however, the contribution of higher values of l_α has the effect of *reducing* the magnitude of the angular distribution coefficients, and therefore the choice of $E2$ radiation for γ_2 is the most likely one.

For γ_3 the choice of $E1$ radiation gives agreement just within the uncertainty in the measurement. Since only one value of l_α is allowed by the selection rules in this case, a closer agreement for A_3 could be obtained only by allowing a large contribution from an incoming $l_p=3$ wave. For $M2$ and $M3$ radiation it is possible to

TABLE III. Computed angular distribution coefficients and polarization ratios for those cases having distributions of the form $1+A\cos^2\theta$. The smallest values of l_p and l_α are used in each case.

Ne^{20}	l_p	O^{16}	l_α	A	P	Possible assignment 6.9-Mev	7.1-Mev
1^+	0	Any	...	0	1	No	No
2^-	1	1^-	2	0.64	0.22	No	Yes
		1^+	1	−0.45	0.38	No	No
		2^-	0	1.00	0.00	No	Yes
		2^+	1	0.43	2.51	Yes	No
		3^-	2	0.24	1.38	Yes	No
		3^+	1	1.29	0.08	No	Yes
3^+	2	1^-	3	0.82	0.10	No	Yes
		1^+	2	−0.44	0.39	No	No
4^-	3	1^-	4	0.89	0.06	No	Yes
		1^+	3	−0.42	0.40	No	No

reduce the theoretical values of A_3 by assuming contributions from higher values of l_α. In both cases, however, the amplitudes of the $l_\alpha+2$ and the l_α waves must be in a ratio greater than 1:2 in order to obtain agreement within the experimental uncertainty.

The selection of $E2$ radiation for γ_2 and the value $A_2=0.30$ are in complete agreement with the results of Seed and French[10] on the directional alpha-gamma correlations. If one uses their parameters, one obtains $A_2=0.32$. For γ_3 Seed and French obtain the assignment of $E1$, and the value $A_3=0.64$ follows from the fact that they find no evidence in their work for $l_p=3$ waves. The discrepancy between 0.64 and the experimental value of 0.41 can undoubtedly be attributed to the uncertainty in the latter value. As noted above, small

TABLE IV. Quantitative comparison of theoretical and experimental angular distribution coefficients.

γ_2 (6.9-Mev)	A_2 Theor.	A_2 Exp.	γ_3 (7.1-Mev)	A_3 Theor.	A_3 Exp.
$E2$	0.43	0.30±0.08	$E1$	0.64	0.41±0.24
$E2$	0.43	0.30±0.08	$M2$	1.00	0.41±0.24
$E2$	0.43	0.28±0.08	$M3$	1.29	0.50±0.29
$E3$	0.24	0.36±0.10	$E1$	0.64	0.21±0.24
$E3$	0.24	0.36±0.10	$M2$	1.00	0.21±0.24
$E3$	0.24	0.35±0.10	$M3$	1.29	0.26±0.31

errors in either A_t or P_t could account for the discrepancy without materially affecting the good agreement for A_2. A value of $A_3 \simeq 0.6$ would of course give rise to a marked polarization for γ_3; the lack of a strong trend in the γ_3 distribution in Fig. 4 must be attributed to the poor resolution coupled with the very low relative intensity of γ_3, and to the poor statistics.

A least-square analysis of the 6.13 distributions presented in Figs. 4(a) and 4(b) yields polarization ratios of $P_1=0.99\pm0.10$ and 0.89 ± 0.08, respectively. Considering the statistical uncertainty and the experimental error (particularly the somewhat anomalous behavior of one plate) the ratio is too close to unity to establish the polarization of the 6.13-Mev gamma ray, and a parity assignment cannot be made. The work of Arnold[13] and Barnes *et al.*[14] on the directional correlation and of French and Newton[4] on the polarization correlation involving this state in O^{16} has, however, established the assignment of 3^- ($E3$ radiation).

An approximately isotropic polarization for the 6.13-Mev gamma ray is expected from the value of $+0.01\pm0.04$ given by Sanders[9] for the angular distribution coefficient. If we use the values found above for the 6.13-Mev polarization ratio, we arrive at values of -0.01 ± 0.08 [from Fig. 4(a)] and -0.09 ± 0.06 [from Fig. 4(b)] for the angular distribution coefficient in essential agreement with Sanders' value.

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[13] W. R. Arnold, Phys. Rev. **80**, 34 (1950).
[14] Barnes, French, and Devons, Nature **166**, 145 (1950).