difficulty for direct interaction to take place in the case of the latter states. The total cross sections, obtained by integration of the differential curves, are somewhat lower for these states, as seen in Fig. 3.

That Coulomb barrier penetration is an essential factor affecting the reaction at these low energies is indicated in Fig. 4. Gamow plots are made of the total cross sections of the four proton groups for *s*-wave deuterons. By neglecting the correction for the finite height of the barrier, one obtains a theoretical slope of 218 compared with an observed value for the combined proton groups of $215\pm7(\text{kev})^{\frac{1}{2}}$.

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Low-Lying Levels in P^{30}†*

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The reaction Al$^{27}(\alpha,n)$P^{30} has been studied at 8.15-Mev bombarding energy using nuclear emulsions as detectors. Neutron groups corresponding to Q values of -2.70, -2.96, -3.59, -4.43, and -4.96 Mev were observed. Comparison of the resulting energy level structure in P^{30} with that obtained by other reactions suggests the possible inversion of the two isobaric spin ground states.

SELF-CONJUGATE odd-odd nuclei in the light mass region provide very favorable subjects for the study of isobaric spin, since they alone have more than one T value among their low-lying states. Of special interest is the study of their level structures to determine the position of the lowest $T=1$, $J=0^+$ state. P^{30}, for instance, has been investigated by several authors.[1–7] The results from S$^{32}(d,\alpha)$P^{30} [1] and Si$^{29}(p,\gamma)$P^{30} [3] in particular tend to identify the ground state as $T=0$, with the lowest $T=1$ level at 680-kev excitation. However, when these results are compared with those of several repeated Al$^{27}(\alpha,n)$Si^{30} reactions,[5–7] it is seen that the level structures disagree beyond the limits of experimental error. The present investigation was an attempt to clarify this situation by a fourth analysis of this same reaction to check the previous data.

A thin aluminum target of 0.16 mg/cm^2 was bombarded with a collimated beam of magnetically analyzed alpha particles from the Yale cyclotron for a total integrated beam current of 7.5 millicoulombs. All charged particles were stopped in a 10-mil thick tantalum shield lined with 28 mg/cm^2 of high-purity gold foil. This latter served to reduce the probability of secondary (α,n) reactions being initiated by elastically scattered alphas in the absorbing ring.

The reaction neutrons were detected as proton recoils in 50 μ Ilford C-2 emulsions placed at scattering angles of 0° back to 162.5° at either side of the beam axis. The apparatus used has been previously described.[8] The detectors were placed normal to the scattering plane and inclined at 5° to the radius, which is the nominal particle direction. For most of the plates exposed, an auxiliary radiator of $\frac{1}{4}$-mil Mylar foil (0.86 mg/cm^2) was placed immediately outside the absorber. The knock-on protons induced in this foil were then collimated by appropriate slits prior to detection in the emulsions.

The emulsions were scanned using a Leitz microprojector at 500× magnification. Only proton recoils ending in the emulsion and making an angle of no more than 10° with respect to the nominal neutron direction were accepted. An average of 1500 tracks were measured on each of the nineteen angles analyzed. A typical proton recoil spectrum is shown in Fig. 1. This particular spectrum was chosen since it illustrates all groups discussed below most clearly. To improve the counting statistics in the region of interest, additional areas of each plate were scanned, measuring only those tracks longer than a given minimum range, such as 60 μ in the case of Fig. 1.

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‡ Bell Telephone Laboratories Predoctoral Fellow.

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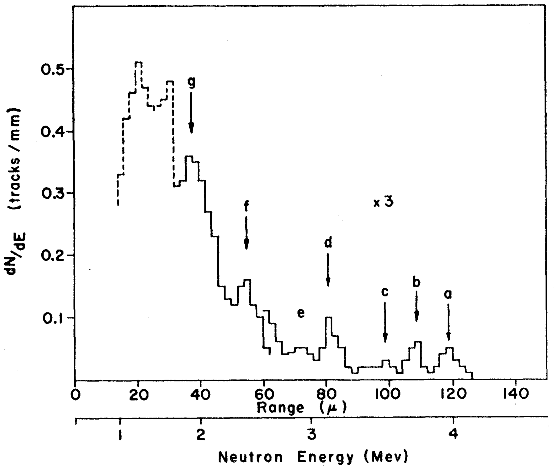

FIG. 1. Histogram of proton recoil spectrum at 102.5°. Groups labeled *a*, *b*, *d*, *f*, *g* are identified with $Al^{27}(\alpha,n)P^{30}$. Group labeled *c* is identified with $A^{27}(d,n)Si^{28}$. Questionable group at *e* is unidentified. Dashed region corresponds to higher excitations not analyzed in this experiment.

The ranges of the observed recoil groups are plotted as a function of laboratory angle in Fig. 2. Comparison of these experimental loci with Q value-parametric curves for the various possible reactions serves to identify the target mass to about 10%. Both likely impurities within this span, Mg^{24} and Si^{28}, have Q values sufficiently negative[9] so as not to effect the present data. The groups labeled *a*, *b*, *d*, *f*, *g* may thus be identified with the $Al^{27}(\alpha,n)P^{30}$ reaction with some degree of confidence. Group *c*, on the other hand, shifts in accordance with a target mass of about 40. Any likely impurities in this region are again ruled out on the basis of highly negative Q's. A second possible source of confusion would be small deuteron contamination of the cyclotron alpha beam. Since (d,n) cross sections are in general so much higher than (α,n) on the same target, as little as 1 particle in 10^3 might prove troublesome. Fortunately, the only group from $Al^{27}(d,n)Si^{28}$ which falls in the region of interest is that corresponding to 9.3-Mev excitation.[9] This would give the dashed curve in Fig. 2. On the basis of the fit shown, group *c* is tentatively explained as arising from deuteron beam contamination. Its relatively weak intensity, in fact nonoccurrence on several plates, would further tend to confirm this identification.

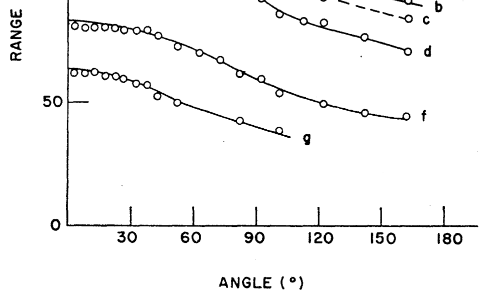

FIG. 2. Ranges of proton recoils *vs* laboratory angle. Solid curves correspond to expected ranges for average Q values. Groups are identified in Table I.

Additional groups were seen on some plates, such as *e* in Fig. 1. However, their location was uncorrelated with angle and their intensities such as to make even their identification as a legitimate group questionable. Groups at higher excitation were also visible, as in the dashed portion of Fig. 1. These were not analyzed, however, because of the necessity of background subtractions and possible further (d,n) interference.

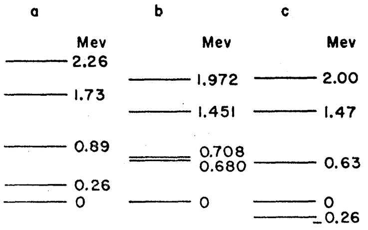

FIG. 3. Comparison of level structure in P^{30} is obtained in $S^{32}(d,\alpha)P^{30}$ (b) with present work, (a) assuming $T=0$ ground state, and (c) assuming $T=1$ ground state. All excitations are given relative to $T=0$ ground state.

The Q values obtained in this analysis are given in Table I. They agree reasonably well with those previously reported.[5] It should be noted however that this earlier work includes several groups (such as *c* and *e*) which are now considered either erroneous or arising from contaminants. In addition the ground-state group had not been found, and energy levels quoted were hence based upon mass value calculations. The present level structure is compared to that reported by Endt and Paris[1] in Fig. 3.

It is evident that if the two ground states are to be considered equivalent, the level structures still do not agree. However, if the level structure as obtained from this reaction is depressed about 260 kev, so as to align the first excited state with Endt and Paris' ground state, then all of the succeeding levels line up reasonably well. Group *d* would then actually correspond to the known doublet at 0.680 and 0.708 Mev. It is unlikely they would be resolved in the present experiment.

This rather curious feature may be explained if one simply assumes that the ground state of P^{30} has an isobaric spin of $T=1$ rather than the usual $T=0$. In the limit of strong isobaric spin selection rules this would inhibit a transition to this state in the $S^{32}(d,\alpha)P^{30}$

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reaction. It is unfortunate that decays to this level were not seen in the $Si^{29}(p,\gamma)P^{30}$ reaction.[8] It is possible, however, that they were overlooked in the necessarily complex fitting of de-excitation gammas into the level structure known from the (d,α) reaction.

Such an inversion as proposed would really not be unusual in P^{30}. Similar inversion is known in Cl^{34},[10] and suspected in K^{38} [11,12] and Sc^{42}.[13] Actually the crossover is expected soon after mass 26.[14] Final confirmation of this suggested interpretation must await a careful re-examination of $Si^{29}(d,n)P^{30}$ and $P^{30}(\beta^+)Si^{30}$ now being undertaken.

The Si^{30}-P^{30} mass difference calculated on the basis of the ground-state Q value of the $Al^{27}(\alpha,p)Si^{30}$ and $Al^{27}(\alpha,n)P^{30}$ reactions is 4.30±0.06 Mev. This compares quite favorably with the reported $P^{30}(\beta^+)Si^{30}$ Q value of 4.26 Mev.[9]

TABLE I. Q values obtained in this analysis.

Group	Reaction	Q (Mev)	Excitation (Mev)	Probable T
a	$Al^{27}(\alpha,n)P^{30}$	-2.70 ± 0.06	0	1
b		-2.96 ± 0.06	0.26	0
d		-3.59 ± 0.06	0.89	1, 0
f		-4.43 ± 0.04	1.73	0
g		-4.96 ± 0.04	2.26	0
c	$Al^{27}(d,n)Si^{28}$	0	···	···

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Photoproduction of Neutral Pions at Energies 600 to 800 Mev*

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The photoproduction of neutral π mesons from hydrogen has been studied at the California Institute of Technology Synchrotron Laboratory by detecting recoil protons from a liquid hydrogen target irradiated by the synchrotron bremsstrahlung beam. The recoil protons were detected by a five-counter telescope. Data were taken at proton laboratory angles of 19°, 30°, 40°, 50°, and 60° at proton energies corresponding to photon energies of 600, 700, and 800 Mev. Angular distribution data are produced at these three energies and fitted with functions of the form: $A+B\cos\theta_\pi'+C\cos^2\theta_\pi'$. These functions are qualitatively like those at lower energies; B is small and $-A/C$ is roughly 1.25. The total cross section is found to have a minimum at about 600 Mev, being slightly larger at 700 and 800 Mev.

I. INTRODUCTION

THE photoproduction of π mesons from hydrogen has been the subject of extensive study at this laboratory and elsewhere.[1] The predominance of a single state of total angular momentum $\frac{3}{2}$ and isotopic spin $\frac{3}{2}$ in the pion-nucleon interaction and use of the scattering phase shifts from pion-nucleon scattering data in a phenomenological model have made possible a satisfactory understanding of meson production by photons up to about 400 Mev.[2] A meson theory calculation by Chew and Low[3] has also been successful in explaining the general features of the process in this energy region.

The experiment described here was carried out to extend the existing data on π^0 photoproduction in hydrogen to higher energies. Little theory currently exists which attempts to explain pion phenomena above about 400 Mev. Still, it is worthwhile to have higher energy data for phenomenological comparisons with charged meson photoproduction and pion-nucleon scattering. Briefly stated, the results of this experiment are that up to 800 Mev the angular distributions are qualitatively the same as at lower energies. The total cross section does not continue to fall rapidly with increasing energy but goes through a minimum at about 600 Mev, and then rises slightly at 700 and 800 Mev.

II. EXPERIMENTAL TECHNIQUE

The method used in this experiment was to count the recoil protons from the reaction $\gamma+p\rightarrow p+\pi^0$ by means of a counter telescope. This method has a good counting rate and is simple, but suffers from the fact

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† Now at Electro-Optical Systems, Inc., Pasadena, California.

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