With this arrangement one observes a pulse-height distribution with a width at half-maximum of 3 Mev corresponding to an energy spread for protons incident on the first crystal of about 20 Mev. This method distinguishes protons from mesons and electrons because, although it is possible for the latter to produce 15-Mev pulses in the back crystal (i.e., stars), they will produce considerably smaller pulses in the front crystal. The energy of those protons counted could be varied by sliding lead absorbers in front of the counting arms as shown in Fig. 1.

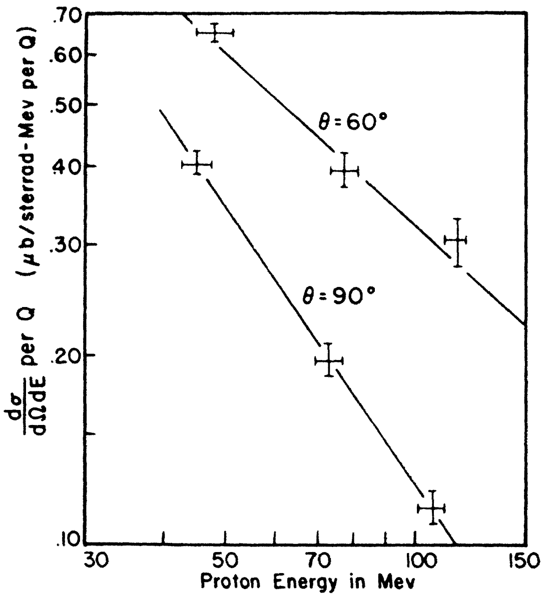

FIG. 2. Cross section *vs* energy for photoprotons from He^4 at 60° and 90° relative to the γ-ray beam.

The counting system was calibrated by observing the number of counts in the proton distribution curve as a function of discriminator bias setting for the back crystal. The number of protons counted should go to zero approximately linearly as the bias setting for the back crystal approaches the value corresponding to the energy thickness of the crystal. This energy was also checked using the ThC″ end point, and the two calibrations agreed. The front crystal was calibrated in a similar manner.

The beam was monitored with an ionization chamber behind one-quarter inch of lead which had previously been calibrated against the pair spectrometer. Measurements were made at 60° and 90° in the laboratory system for three proton energies at a gas pressure of 1800 lb/in.[2] The cross sections given in Fig. 1 are plotted in μb/sterrad-Mev per effective quantum, since there are at least three reactions which yield protons, viz:

(a) $\gamma+He^4\rightarrow H^3+p$,
(b) $\gamma+He^4\rightarrow p+n+H^2$,
(c) $\gamma+He^4\rightarrow p+p+n+n$.

If we assume that the predominant reaction is (a), the cross sections at 101° in the c.m. system per photon are $d\sigma/d\Omega=25$, 17, and 14μb at γ-ray energies of 78, 112, and 153 Mev, respectively.

It should be noted that the resolution of the arrangement was not sufficient to distinguish between protons, deuterons, and tritons; however, energetic considerations show that the heavier particles should contribute only a small fraction of the observed coincidences.

The errors given in Fig. 2 are relative errors. The error to be assigned to the absolute cross sections is 30 percent.

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The Nature of the Second-Order Transition in ND_4Br

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SECOND-ORDER phase transitions in the ammonium halides have been interpreted as the onset of free rotation[1] or of orientational disorder[2] of ammonium ions. Recent spectroscopic evidence[3] supports the latter hypothesis. We have obtained direct evidence also favoring the disorder hypothesis from complete crystal structure determinations of two phases of ND_4Br by means of neutron diffraction. A contrary result in ND_4Cl was recently reported by Goldschmidt and Hurst[4] from a neutron diffraction study of that material.

ND_4Br undergoes the following changes[5] as the temperature is lowered:

$$\text{f.c. cubic} \xrightarrow{\sim 125^\circ} \text{simple cubic (CsCl type)} \xrightarrow[\text{second order}]{-58.4^\circ}$$
$$\text{tetragonal} \xrightarrow{-105^\circ} \text{simple cubic (CsCl type).}$$

Neutron diffraction data from all four phases have been collected, and those of the two CsCl-type structures have been analyzed in detail. Scattering cross sections used were those reported by Shull and Wollan.[6] Observed data and comparison with calculation are presented in Table I.

TABLE I. Neutron diffraction data[a] from ammonium bromide.

	Low temperature phase			Room temperature phase		
Indices	Calc.	Obs.	Uncertainty	Calc.	Obs.	Uncertainty
100	17.9	17.9	±0.4	17.8	17.7	±0.35
110	72.0	72.3	1.4	67.5	67.3	1.3
111	15.4	16.1	0.8	3.9	3.6	0.4
200	5.4	5.0	0.6	6.2	6.8	0.7
210	0.6	1.7	1.0	0.2	0	1.0
211	84.5	87.1	2.4	32.0	32.1	1.6
220	31.1	30.8	2.0	18.9	19.5	1.4
221–300	79.1	76.0	3.5	8.7	7.8	0.8
310	2.4	4.1	2.1	3.9	3.7	1.8
311	13.1	13.3	3.5	3.0	3.0	1.5
222	43.3	41.5	8	11.3	11.3	1.7
320	8.4	5.8	4	2.0	3.7	1.8
321	159.5	163.2	8	72.8	77.8	5.8
400	0.2	0	1	0.1	0	1.0
410–322	27.2	27.4	3	4.8	6.1	3.0
411–330	124.1	117.5	15	45.9	48.0	4.8
331	27.5	33.4	15	6.8	9.6	4.8
420	77.7	93.2	15	31.3	36.9	5.5
421	23.4	40.9	15	2.5	5.2	2.6
332	32.0	25.0	10	18.8	18.1	2.7

[a] The quantities listed are the square of the structure factor multiplied by the multiplicity of the reflection, jF^2. The calculated values are for the final models and include the effects of temperature motion. Intensities were measured on an absolute scale, so that absolute as well as relative agreement is significant.

The phase at −195°C was found to give a simple cubic pattern with $a_0=3.96$A. Peak intensities were satisfactorily matched by calculation from a model conforming to symmetry T_d^1 with deuterium atoms placed in fourfold positions (e),[7] along the body diagonals of the cube. The required temperature factor for deuterium corresponded to a mean amplitude of vibration of about 0.14A. Thus, the lowest temperature phase consists of an ordered structure closely similar to that found for low temperature ND_4Cl.

The room temperature pattern corresponds to a simple cubic unit with $a_0=4.05$A. The model which gave satisfactory agreement placed the four deuterium atoms at random in the eightfold positions (g) of space group O_h^1, corresponding to twofold randomness in the orientation of the tetrahedral ammonium ions. The model required anisotropic temperature motion of the deuterium atoms, the distribution being greatly extended in directions near the plane normal to the N−D link. This anisotropy could result from torsional oscillation of the ammonium ion about the two equilibrium orientations in its cubic cage of bromide ions. In the simplified model used for calculation, each deuterium was treated as a spherical cloud whose center was distributed with uniform probability around a circle centered on the cube body diagonal, the root-mean-square radius of the cloud and the half-angle subtended by the circle at the nitrogen atom being treated as parameters whose final values were 0.21A and 10°, respectively. Models involving ordered structures of symmetry T_d^1 with or without anisotropic temperature motion and models with freely rotating ammonium ions failed to give agreement with the data. Also eliminated were models in which the ammonium ions rotate about their twofold axes, space group O_h^1, and about their threefold axes with and without randomness of orientation, space group T_d^1 and O_h^1 (simulated), respectively.

Thus, in room-temperature ND_4Br there exists orientational disorder of the ammonium ions, and the crystal belongs to symmetry class O_h, simulating the space-group symmetry O_h^1. The reported chloride structure, in contrast, is ordered, with symmetry T_d^1, although involving temperature motion similar to that found in ND_4Br. This difference between the room temperature phases of ND_4Br and ND_4Cl is surprising and calls for further study to confirm its reality. A disagreement exists on the value of the coherent scattering cross section of deuterium (5.2 barns[6] in this work *versus* 5.8 used in reference 4). We find that use of the latter value does not change our conclusions with regard to the nature of the structure; however definitely better agreement is achieved with the value 5.2.

Our study yields the values 0.99±0.02A for the length of the N−D link, equal within experimental uncertainty in both phases. Further work on the atomic arrangements in the two remaining phases is planned. A complete description will be published elsewhere.

* This work was performed for the Atomic Energy Commission.
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The Spins and Parities of the 3.7–3.9-Mev Doublet in C^{13}

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THE energy of the nuclear level of C^{13}, following after the 3.11-Mev state, has been variously given in the literature as 3.7 and 3.9 Mev. Thus Heydenburg *et al.*[1] in a study of the protons from $C^{12}(d, p)C^{13}$ give the energy value of the state as 3.91 Mev, while recently Malm and Buechner,[2] in a careful measurement of the alpha-particles from $N^{15}(d, \alpha)C^{13}$, found a value of 3.68 Mev. Actually both of these values are nearly correct. In a detailed study of the protons from the $C^{12}(d, p)C^{13}$ reaction, using an 8-Mev deuteron beam and employing the photographic emulsion technique for recording the protons (the experimental arrangement is described by Rotblat *et al.*)[3] two groups of protons, of slightly different ranges, were found to be present in this energy region, indicating the existence of two closely lying levels in C^{13}. The protons of longer range have a much lower intensity than those of the shorter range; at some angles the intensity of the former is only 2 percent of that of the latter. For this reason the longer range group tends to be lost in the "tail" of the more intense group. Nevertheless, after measuring a large number of tracks at 20 angles of emission and analyzing the histograms of the proton groups, the existence of both levels has been established beyond doubt. The Q-values for the two states were found to be −0.967 and −1.168 Mev; assuming a Q-value for the ground state of 2.716 Mev[4] we obtain for the energy values of the two states 3.683 and 3.884 Mev. It is possible that these correspond to the states which were observed by Creagan[5] from the $B^{10}(\alpha, p)C^{13}$ reaction and for which he gave values 3.76 and 4.00 Mev. It is also interesting to note that, unlike the $C^{12}(d, p)$ process in which the 3.7-Mev level is formed relatively rarely, in the $N^{15}(d, \alpha)$ reaction this level appears to be formed predominantly.

Apart from establishing the existence of the doublet, the angular distributions of the two groups of protons have also been investigated. According to Butler's[6] stripping process the spins and parities of the corresponding nuclear states can be determined

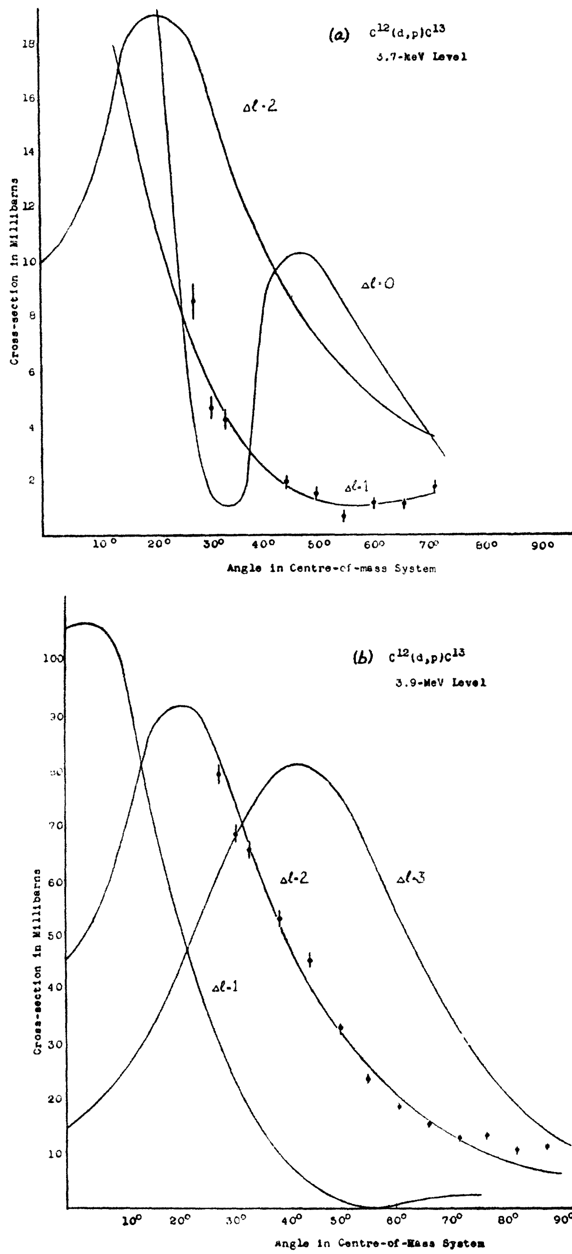

FIG. 1. Angular distributions of protons from $C^{12}(d, p)C^{13}$ in the center-of-mass system. The full curves give the theoretical distributions for various values of the angular momentum transfer. The experimental points are given with their probable errors. Figure 1(a) is for the formation of C^{13} in the 3.7-Mev state and Fig. 1(b) for the 3.9-Mev state.