cross section for this process has the behavior

$$\sigma \sim |\varphi(n)|^4 \left(\frac{4mB}{3\hbar^2}+n^2\right)^2, \tag{17a}$$

$$n=|\mathbf{k}_1+\tfrac{1}{3}\mathbf{k}_2|. \tag{17b}$$

For a proton energy (laboratory) E_0, one readily finds $n^2=E_0(5+3\cos\theta)/8$, where θ is the angle between $\mathbf{k}_1$ and $\mathbf{k}_2$, and n^2 is here expressed in energy units.

Calculations have been made from (17a) for the angular distribution resulting from the stripping process. For convenience in the calculation $u(r)$ was taken to be a Hulthén function $(e^{-\alpha r}-e^{-\beta r})/r$, with α determined from the binding energy and β taken as 1.7α, a value which makes $u''=0$ for $r=3.5\times10^{-13}$ cm. This approximation to u probably has too strong high-momentum components.

The results of using this approximation are compared with the experimental data, in Fig. 3. The theoretical peaks are broader than the experimental ones. At least part of this difference could be made up by taking a u "smoother" than the one used, while still having proper asymptotic behavior. It does not seem worthwhile to pursue this, since the peak could also be narrowed by interference effects between $|V_{pn}|$ and $|V_{pN}|$, and since the entire calculation is only approximate. (The rather sharply-featured dip in the angular distribution is suggestive of interference effects, but could also be produced by a model in which H^3 and He^3 are taken to be partially opaque rather than completely transparent.) The essential conclusion to be drawn from the present work is that the major features of the data can be accounted for on the rearrangement-collision viewpoint.

The results of this work are of interest from two standpoints. Firstly, the $H^3(p,n)$ reaction data have been considered to give the principal evidence for the existence of an excited (although unbound) state of He^4. From the results of the present work, the $H^3(p,n)$ data do not provide such evidence for a state of He^4, and thus they give no evidence for the existence of a state of H^4 at corresponding energy. The existence of these states would be important for the interpretation of certain scattering and hyperfragment data.

Secondly, this work provides additional evidence that the Born approximation can give a good account of nuclear re-arrangement collisions, even at energies as low as a few Mev. This result is of interest because it is difficult to establish a criterion for the validity of the Born approximation in a rearrangement collision—no such simple criterion can be stated as can be, for example, for the use of the Born approximation in simple scattering. The results of the present work add to previous evidence that the Born approximation can give a good account of the angular and energy variations in rearrangement collisions, although the absolute values may not be given with much accuracy.

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Spin of N^{16}†

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Observations have been made on the intensity ratio of the 6.13- to 7.11-Mev gamma rays of O^{16} following decay of N^{16} in order to test the possibility that the ground and first excited states of N^{16} have spin 0− and 3− as preliminary results of recent calculations by Elliott have predicted. The ratio was obtained with N^{16} made by the $O^{16}(n,p)N^{16}$ reaction and by the $F^{19}(n,\alpha)N^{16}$ reaction. For the first reaction, the ratio was obtained for two ages of the N^{16}. The constancy of the resulting intensity ratios implies that the theoretical prediction is not correct.

THE spin of N^{16} is commonly taken to be 2− on the basis of the character of the beta decay to the ground state and excited states of O^{16}.[1] Preliminary results of recent calculations by Elliott at Harwell predicted[2] four low-lying states (including the ground state) in agreement with experiment. These states were found all to have negative parity with spins 0, 3, 2, and 1 but the order was unreliable because of their closeness. Although the same calculations gave good agreement for the odd-parity levels and gamma-decay branching ratios in O^{16}, there appeared to be a serious disagreement in the beta decay of N^{16} to O^{16}. Assuming N^{16} to have 2− for its ground state gave reasonable agreement for the ft values to the O^{16} 2− state at 8.87 Mev[3] and the 3− state at 6.13 Mev,[4] but there was a factor of the order of 10^3 between theory and experiment for the ft value to the 1− state at 7.11 Mev.[4]

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[1] Millar, Bartholomew, and Kinsey, Phys. Rev. **81**, 150 (1951).
[2] D. H. Wilkinson, private communication.
[3] Wilkinson, Toppel, and Alburger, Phys. Rev. **101**, 673 (1956).
[4] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

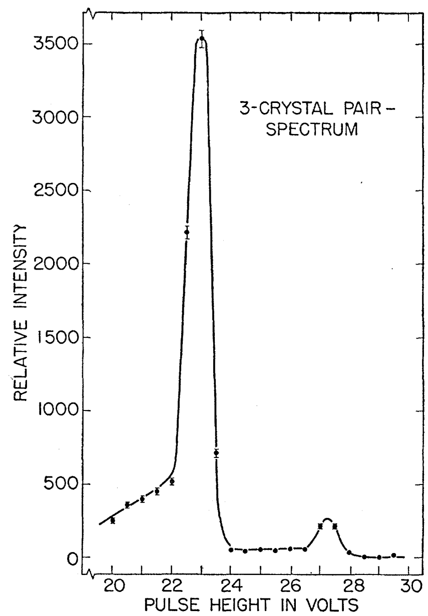

FIG. 1. Three-crystal pair spectrum showing the 6.13-Mev and 7.11-Mev O^{16} gamma rays following decay of N^{16}.

Elliott noticed that this discrepancy could be removed if in fact N^{16} had spins 0 and 3 for its two lowest levels. These states would both decay by beta emission since the *M*3 isomeric transition would have a single particle speed of about 4000 seconds (assuming an energy of 113 kev[4]). According to the theory, the 0− level would decay to the O^{16} 0+ ground state and 1− state, while the 3− level would decay to the 2− and 3− states. The lifetimes for these two transitions would be, extremely roughly, 5 and 20 seconds, respectively, which are to be compared with the apparent over-all lifetime of 7.35 seconds.

In order to investigate this possibility, observations were made of the intensity ratio of the 6.13- to 7.11-Mev O^{16} gamma rays both as a function of the age of the N^{16} and the reaction producing it. Presumably the 0− and 3− states of N^{16} would not have exactly the same half-life nor would they be populated the same in different reactions. The gamma rays were detected by a three-crystal pair spectrometer and the data were recorded using an Atomic Instrument Company 20-channel pulse-height analyzer.

A constant source of N^{16} activity was first obtained by means of the $O^{16}(n,p)N^{16}$ reaction by using a continuous flow water target with $Li^7(d,n)$ neutrons from the Brookhaven National Laboratory research Van de Graaff generator. After irradiation, the water flowed through small diameter copper tubing to a nearby laboratory for observation. By inserting a length of large-diameter tubing in series with the small tubing so as to hold up a given unit volume while not affecting the gross flow rate, one can effectively let the N^{16} decay before counting. Two observations were made using a flow of 5.1 seconds per cubic inch. With the "delay" in, the intensity fell by a factor of 2.95 while there was no apparent change in the flow rate. Assuming a 7.35-second half-life, the hold-up then amounts to 11.5 seconds. The observed 6:7-Mev intensities are 14.5:1 without holdup and 14.9:1 with holdup, each to a statistical uncertainty of about 7%. The intensities were calculated by determining the peak height, correcting for width, and dividing by the pair cross section.[5] Figure 1 shows a typical three-crystal pair spectrum taken without holdup. The other data are similar.

From these results, one concludes that either the 3− and 0− states have the same half-lives with a probable error of ±7% or that only *one* state is involved. Since the 6.13-Mev 3− state of O^{16} is strongly fed, the N^{16} state feeding it could not be of spin 0−. Also, a 3− N^{16} state would not feed the 1− O^{16} state at 7.11 Mev. One might perhaps hope then that the upper small peak of Fig. 1 is not due to a 7.11-Mev gamma ray but rather to a gamma ray of energy 6.91 Mev. This is already doubtful from the observed intensities since a 3− to 2+ beta transition is first forbidden. However, in order to check this possibility, a careful determination was made of the energy of the "7-Mev" gamma ray relative to the known 6.13-Mev gamma ray. This determination was made using a technique similar to the earlier runs but with higher dispersion. Assuming an energy of 6.130 Mev for the prominent gamma ray, the resulting energy was found to be 7.116±0.020 Mev. One must therefore conclude that if *one* state is involved in the decay of N^{16}, it cannot have spin 0− or 3−.

N^{16} was next made by means of the $F^{19}(n,\alpha)N^{16}$ reaction. Teflon targets were used and neutrons were produced using 2.3-Mev deuterons on a deuterium gas target. Since in this case the detectors were situated in the intense neutron flux, data could be recorded only with beam off target. The Van de Graaff generator and scalers were alternately activated and deactivated by means of a one-cycle-per-minute motor and cam-relay system. Beam was on target for about 30 seconds and then scalers were activated for about 25 seconds with beam off, and so on. It was not found necessary to remove high voltage from the photomultipliers during the neutron irradiation. The data obtained were similar to Fig. 1 and a ratio of 14.3:1 was found for the 6:7-Mev intensities with the same uncertainty as before. This ratio and the previous two can be compared with the earlier 12.5±3.1 of Millar *et al.*[1]

Excepting the improbable coincidence that the theorized 0− and 3− states of N^{16} have the same half-lives against beta decay and that they are populated the same in two reactions within about ±7%, one must conclude that only a single state of spin 2− is involved in the decay of N^{16}.

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[5] Mann, Meyerhof, and West, Phys. Rev. **92**, 1481 (1953).