tervals of one hour for the first 9 traps. The activity of each sample of iodine grown in from the xenon was determined. The last trap was sealed and mounted for counting immediately upon transferring the xenon to it. From 3 to 5 minutes elapsed from the starting of a parent-daughter separation and the placing of the iodine sample under the scintillation counter.

All iodine daughter samples showed the presence of 3.4(±0.1)-minute and 1.45(±0.1)-hour activities, presumably $I^{122}$ and $I^{121}$, respectively, 13-hour $I^{123}$, and 17-day $Te^{121}$. Several determinations of the $I^{121}$ half-life on radiochemically pure iodine separated from the target gave a value of 1.5(±0.1) hours rather than the reported 1.8 hours, and the tellurium activity isolated from these samples confirmed the observation[3] that $I^{121}$ decays to the lower 17-day isomeric state of $Te^{121}$. From the yields of $I^{121}$ and $I^{123}$ *versus* the time of parent-daughter separations the half-lives of $Xe^{121}$ and $Xe^{123}$ were determined to be 40(±2) minutes and 1.7(±0.2) hours, respectively (curves *A* and *C*, Fig. 1). The yields of $I^{122}$ (curve *B*) proved to be completely compatible with the half-life of 20(±1) hours found with a GM tube for the xenon in the last trap of the series. Scintillation counter data on this sample proved that 32-day $Xe^{127}$ had also been produced and indicated that 18-hour $Xe^{125}$ was likewise present. All limits of error placed on numerical values are based on an estimate of the apparent reliability of the data.

Other workers, Tilley[4] at McGill University and Mathur and Hyde[5] at the University of California, Berkeley, have independently obtained information in substantial agreement with ours.

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## Angular Correlations in $(d,p\gamma)$ Reactions*

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THE angular distribution of protons produced in $(d, p)$ reactions has been calculated by Butler[1] and others[2,3] under the assumption that a stripping process is the primary mechanism operative. Comparison of this theory with experimental results for the proton distribution makes it possible, in many cases, to determine the angular momentum $l_N$ transferred to the target nucleus by the capture of a neutron. In general, the information obtained about $l_N$ does not provide a unique spin assignment for the resultant nucleus; a parity determination is always unambiguous. If a target nucleus of spin $\mathbf{j}_0$ captures a neutron with orbital angular momentum $l_N$ from the deuteron, the spin of the resultant nucleus $\mathbf{j}_1$ is restricted to the values

$$|\mathbf{j}_0+\mathbf{l}_N+\tfrac{1}{2}|_{\min}\leqq j_1\leqq j_0+l_N+\tfrac{1}{2}. \quad (1)$$

The production of a nucleus $(j_1)$ from a target nucleus $(j_0)$ may be characterized by several values of $l_N$ provided these values differ by an even number of units and obey the limiting relation

$$|\mathbf{j}_0+\mathbf{j}_1+\tfrac{1}{2}|_{\min}\leqq l_N\leqq j_0+j_1+\tfrac{1}{2}. \quad (2)$$

It is to be noted that if either $j_0$ or $j_1$ are zero, only one value of $l_N$ contributes to the reaction.

The methods and approximations applied in the $(d, p)$ stripping calculations can be extended to the $(d, p\gamma)$ correlation function. The correlation function $f(\theta, \vartheta)$ takes the form

$$f(\theta, \vartheta)=\text{const}\sum_{l_N}\frac{\Lambda_{l_N}(\vartheta)}{(2l_N+1)}|g_{l_N}(\theta)|^2. \quad (3)$$

$|g_{l_N}(\theta)|^2$ is the angular distribution with respect to the incoming deuteron of the protons produced in the absorption of a neutron $(l_N)$ from the deuteron by the target nucleus $(j_0)$ leading to the nuclear state $(j_1)$. $\Lambda_{l_N}(\vartheta)$ is the angular correlation function for the $(n, \gamma)$ reaction in which a free neutron of angular momentum $l_N$ is absorbed by a target nucleus $(j_0)$ leading to a new nucleus $(j_1)$ in the excited state which subsequently decays by $2^L$ multipole emission to the nuclear state $(j_2)$. $\vartheta$ is the angle between the directions of propagation of the absorbed neutron and the emitted $\gamma$-ray. $\Lambda_{l_N}(\vartheta)$ is explicitly[4]

$$\Lambda_{l_N}=\sum_{\sigma}\sum_{m_1m_2}|A_{\sigma}{}^{l_N}|^2 \times\langle\sigma l_N m_1 0|j_1m_1\rangle^2\langle j_1Lm_1(m_2-m_1)|j_2m_2\rangle^2F_L{}^{m_2-m_1}(\vartheta). \quad (4)$$

$\sigma$ is the vector sum of $\mathbf{j}_0$ and $\mathbf{S}_N$ (neutron spin); $A_{\sigma}{}^{l_N}$ is that part of the matrix element for the neutron capture process exclusive of the Clebsch-Gordan coefficients representing the dependence on the magnetic quantum numbers; $F_L{}^{m_2-m_1}(\vartheta)$ is the classical distribution for the $(m_2-m_1)$ contribution to the $2^L$ multipole radiation; $m_1$, $m_2$ are the sets of magnetic quantum numbers belonging to the states $(j_1)$ and $(j_2)$, respectively. It immediately follows that if the $(d, p)$ process is characterized by only one value of $l_N$, the emitted $\gamma$-ray is correlated to the direction of the absorbed neutron—or what is equivalent, the direction of the recoiling nucleus $(j_1)$—just as if the neutron had been captured from an unbound state.[5] This obtains when $j_0=0$ and Eq. (3) becomes

$$f(\theta, \vartheta)=\text{const}|g_{l_N}(\theta)|^2 \times\sum_{m_1m_2}\langle j_1Lm_1(m_2-m_1)|j_2m_2\rangle^2F_L{}^{m_2-m_1}(\vartheta)\delta(m_1\pm\tfrac{1}{2}). \quad (5)$$

Equation (5) exhibits no unknown parameters except those contained in the internal wave function of the deuteron implicit in $g_{l_N}(\theta)$. For the general reaction in which $j_0\neq 0$, no statements can be made concerning $f(\theta, \vartheta)$ which are independent of a specific nuclear model needed to calculate the functions $A_{\sigma}{}^{l_N}$.

Equation (5) can be applied directly to the $A^{40}(d, p)A^{41*}(\gamma)A^{41}$ reaction, which has been studied experimentally by Gibson and Thomas.[6] These authors have demonstrated that the 1.34-Mev state of $A^{41}$ has either odd parity and spin $\frac{1}{2}$ or $\frac{3}{2}$, or possibly even parity and spin $\frac{1}{2}$, whereas the ground state has spin 7/2 or 5/2 and odd parity. Table I gives the dependence on $\cos\vartheta$ of the angular correlation function $f(\theta, \vartheta)$ for each possible assignment of spin and parity to the 1.34-Mev and ground states of $A^{41}$. It is to be noted that if the measured angular correlation function is isotropic, the 1.34-Mev state has spin $\frac{1}{2}$, but no definite statements can be made of its parity or the spin of the ground state. On the other hand, a measured angular correlation which is nonisotropic will determine the spins and parities of both states of $A^{41}$.

TABLE I. Predicted angular distribution of $\gamma$-rays from the 1.34-Mev level of $A^{41*}$ formed in a $(d, p)$ reaction on $A^{40}$. $\vartheta$ is the angle between the recoiling $A^{41*}$ and the 1.34-Mev $\gamma$-ray; $L$ is the pole of the emitted $\gamma$-ray.

| $A^{41*}$ spin | $A^{41*}$ parity | $A^{41}$ spin | $A^{41}$ parity | $L$ | $f(\theta, \vartheta)/\lvert g_{l_N}(\theta)\rvert^2$ |
|---|---|---|---|---|---|
| 1/2 | odd | 7/2 | odd | arbitrary | 1 |
| | | 5/2 | odd | | |
| 1/2 | even | 7/2 | odd | | |
| | | 5/2 | odd | | |
| 3/2 | even | 7/2 | odd | 2 | $1+(3/13)\cos^2\vartheta$ |
| | | 5/2 | odd | 1<br>2 | $1-(1/7)\cos^2\vartheta$<br>$1-(5/11)\cos^2\vartheta$ |

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