to the following transitions:

Kr: $3d^{10}4s^24p^6\,{}^1S_0 - 3d^94s^24p^6({}^2D_{3/2,5/2})np\,{}^1P_1{}^\circ$,

Xe: $4d^{10}5s^25p^6\,{}^1S_0 - 4d^95s^25p^6({}^2D_{3/2,5/2})np\,{}^1P_1{}^\circ$.

The excitation of inner d-shell electrons was observed by Beutler[7] for the elements Zn, Cd, and Hg. He observed structure in the 600-1200Å region, due to such transitions as $5d^{10}6s^2\,{}^1S_0 - 5d^9 \times 6s^2np\,{}^1P_1{}^\circ$ in Hg. These levels, however, lie only 1-9 eV above the first ionization limit since the outer p shell is vacant. Beutler also observed weaker series of lines due to such transitions as $5d^{10}6s^2\,{}^1S_0 - 5d^96s^2nf\,{}^1P_1{}^\circ$. In the case of Kr and Xe, $d \rightarrow f$ excitation has not been observed.

This Letter reports the excitation of more deeply seated electrons than has been previously observed in neutral atoms by means of optical atomic spectroscopy. At higher energies similar types of excitation are observed as fine structure near the x-ray absorption edges of inner electrons. Most x-ray observations involve atoms in the solid state where this fine structure is broadened and highly modified. In any case, the resolution and accuracy available with x-ray spectroscopy in analyzing such fine structure is not competitive with that available in these experiments.

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EXPERIMENTAL EVIDENCE FOR J DEPENDENCE OF THE ANGULAR DISTRIBUTION FROM (d,p) REACTIONS*

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The (d,p) reaction has been extremely useful as a spectroscopic tool in investigating energy levels in nuclei—largely because of Butler's discovery[1] that the position of the forward peak in the angular distribution of a (d,p) reaction is a unique way of determining the orbital angular momentum l of the captured neutron.

As a result, a large body of experimental data on angular distributions from (d,p) reactions has been accumulated and much has been learned about the spins and parities of energy levels in light and medium-weight nuclei. However, the knowledge of the orbital angular momentum l does not allow a unique assignment of the total angular momentum J of the final state. At best, for even-even spin-0^+ target nuclei, it can specify J to within one unit. Thus $l=1$ on such a target would imply $J=\frac{1}{2}^-$ or $\frac{3}{2}^-$. The choice between the two possibilities requires additional information such as the angular correlation in a $(d,p\gamma)$ reaction. A knowledge of J is essential to a meaningful comparison with theories of nuclear structure.

We have studied the $l=1$ angular distributions from a series of (d,p) reactions for which the target nucleus had spin 0^+, and the spin of the final state in the product nucleus had already been uniquely determined to be $\frac{1}{2}^-$ or $\frac{3}{2}^-$ by gamma-ray correlation measurements.[2-5] Our measurements indicate the rather surprising result that there is a distinct difference between the angular distributions for $\frac{1}{2}^-$ and $\frac{3}{2}^-$ final states. Data for three $l=1$ states seen in $^{40}Ca(d,p)^{41}Ca$ are shown in Fig. 1. The $\frac{1}{2}^-$ state shows a pronounced dip at 100°, the two $\frac{3}{2}^-$ states show no such effect. Figure 2 shows angular distributions for the ground state and first excited state of ^{55}Fe observed in the $^{54}Fe(d,p)^{55}Fe$ reaction. The $\frac{1}{2}^-$ excited state shows a sharp dip at 132° while no such effect is observed for the $\frac{3}{2}^-$ ground state. A total of 19 final states with $l=1$ and known J were investigated at a deuteron energy of 10 MeV. All the $\frac{1}{2}^-$ states exhibited a sharp minimum in the backward angular distribution while none of

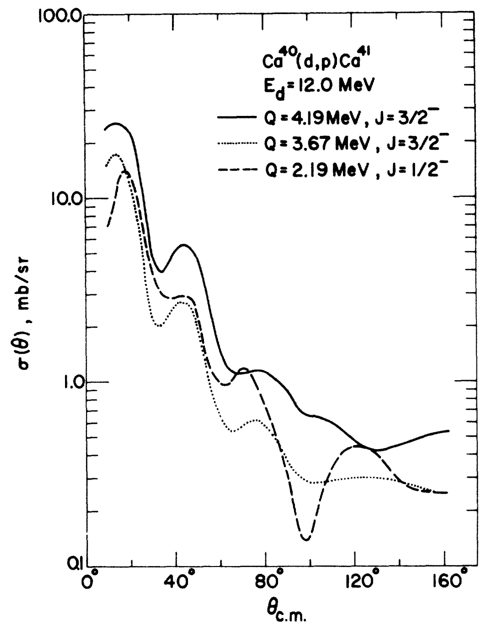

FIG. 1. Angular distributions of protons for three $l = 1$ states from the $^{40}Ca(d,p)^{41}Ca$ reaction. Points in the angular distributions are at 5° intervals; errors in the cross sections are less than 10%.

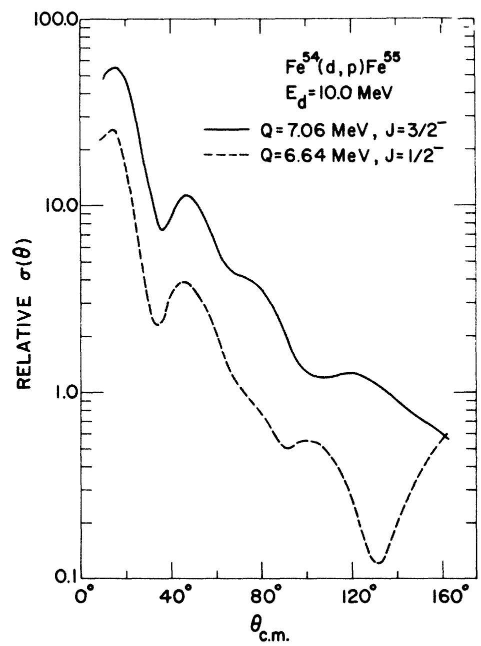

FIG. 2. Angular distributions of protons from the $^{54}Fe(d,p)^{55}Fe$ reaction leading to the ground states and first excited state of ^{55}Fe. Points in the angular distributions are at 7.5° intervals; the errors in the cross sections are less than 10%.

the $\frac{3}{2}^-$ states showed such an effect. These results are summarized in Table I where the ratio of cross sections, the angular position of the minimum, and the spins of the states are tabulated.

It is clear from Table I that this striking behavior of the angular distributions is confirmed in every case. The effect appears at all energies at which it has been studied, 8- to 12-MeV deuterons on ^{40}Ca and ^{54}Fe, although the minimum is less pronounced at 8 MeV than it is at 10. The reason for this minimum may possibly be that the spin-orbit potential induces slight differences in the captured neutron wave function, or spin-dependent differences in the distortions for incoming deuterons and the outgoing protons may account for this effect. It is interesting to note that the minimum is at 100° in ^{40}Ca and at 135° ± 3° for all the other targets. This may possibly be associated with the fact that the parameters of the optical potential[6] required to fit the elastic deuteron scattering from ^{40}Ca are qualitatively

Table I. States of known J for which the backward angular distributions have been studied in the (d,p) reaction. The angle θ_{min} at which the backward minimum occurs for $J = \frac{1}{2}$ states, and the value of $R = \sigma(\theta_{min})/\frac{1}{2}[\sigma(\theta_{min} - 25°) + \sigma(\theta_{min} + 25°)]$ are given.

Target	Energy of excited state (MeV)	Spin	θ_{min}	R
^{40}Ca	1.95	3/2		1.1
	2.47	3/2[a]		1.1
	3.95	1/2[a]	100°	0.2
^{48}Ti	1.38	3/2[b]		1.0
^{54}Fe	0.0	3/2		1.4
	0.41	1/2[c]	132°	0.3
	2.49	3/2[c]		1.4
	3.56	3/2[c]		1.3
	3.80	3/2[c]		1.5
^{58}Ni	0.0	3/2		1.1
	0.47	1/2[d]	135°	0.4
	0.89	3/2[d]		1.0
	1.32	1/2[d]		0.3
^{60}Ni	0.0	3/2[d]		1.1
	0.29	1/2[d]	135°	0.3
^{62}Ni	0.0	(1/2)	137°	0.35
	0.16	3/2[d]		0.93
	0.53	3/2[d]		0.87
	1.01	1/2[d]		0.29

[a]See reference 2.
[b]See reference 3.
[c]See reference 4.
[d]See reference 5.

different from those for Ti, Ni, Fe, and other heavier nuclei.[7] It is not yet clear to what extent similar effects may be present in nuclei outside the mass range $40<A<64$, although experiments on light nuclei do not seem to show this trend. It is also not clear whether such effects would persist for $l>1$ or target nuclei with nonzero spin. For $l=1$ and $40<A<64$, however, the effect is reasonably well confirmed empirically. We have therefore started to use this effect in an effort to determine the spins of states in this mass region in even-odd nuclei for which other experiments[8-10] have shown that $l=1$. The same type of characteristic difference in angular distributions around $\theta\approx 135°$ have been observed for 10 of the states studied. These results and the values they indicate for the spin J are given in Table II. Further measurements of this type are in progress.

Table II. States of unknown J for which an $l=1$ angular distribution has been observed in other experiments. Values of θ_{min} and R as defined in the caption of Table I are given.

Target	Energy of excited state (MeV)	Source of $l=1$ information	θ_{min}	R	Assigned J
^{46}Ti	1.56	a		1.0	3/2
	1.80	a	135°	0.45	1/2
	3.31	a		1.1	3/2
	3.71	a		0.85	3/2
	3.95	a		1.1	3/2
^{50}Ti	0.0	b		0.8	3/2
	1.16	b	137°	0.4	1/2
	2.13	b		0.8	3/2
^{60}Ni	1.105	c	135°	0.4	1/2
	1.195	c		0.8	3/2

[a]See reference 8.
[b]See reference 9.
[c]See reference 10.

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μ CAPTURE BY ^{3}He: PARTIAL AND TOTAL RATES

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Much interest attaches to the reactions resulting from μ capture by ^{3}He. While mesonic-molecular processes tend to obscure the theoretical interpretation of experiments on muon capture in hydrogen, this confusion is avoided for the light nucleus ^{3}He. In this note, we present results of calculations for the capture rates of the reactions

$$\mu^- + {}^3\text{He} \to {}^3\text{H} + \nu, \qquad \text{(a)}$$
$$\to n + d + \nu, \qquad \text{(b)}$$
$$\to n + n + p + \nu. \qquad \text{(c)}$$

The calculations are based on the Primakoff theory,[1] and we include the so-called relativistic terms of his effective Hamiltonian. The wave function used for the trion (generic term for the ^{3}He-^{3}H isotopic doublet) is that due to Pappademos[2] which is of the form

$$\Psi = \prod_{i<j} F(r_{ij}),$$

where r_{ij} denotes the separation between nucle-