waveguide and used for Zeeman modulation. The modulating current consists of a 100-kc/sec sine wave current superimposed on a direct current, in such ratio that the minimum of the sin wave corresponds to zero current. With a modulator whose maximum output was 25 peak-to-peak amperes, adequate modulation fields were obtained for both $^2\Pi_{1/2}$ and $^2\Pi_{3/2}$ states of OH. This technique for Zeeman modulation can also be applied to a standard Stark cell with the Stark septum acting as the center conductor.

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EVIDENCE FOR SHELL-MODEL STATES IN Sc^{41}†

C. M. Class, R. H. Davis,* and J. H. Johnson
The Rice Institute, Houston, Texas
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The excited states of the mirror nuclei Ca^{41} and Sc^{41} are of considerable interest because of the possibilities they present for testing the predictions of the shell model under quite favorable circumstances. According to this model, the ground states of these nuclei are described by single particles in the $f_{7/2}$ shell outside a Ca^{40} core described by closed $(1s)^4(1p)^{12}(1d,2s)^{24}$ shells. Single-particle excited states are predicted approximately in the order $p_{3/2}$, $p_{1/2}$, $f_{5/2}$, $g_{9/2}$, $d_{5/2}$, and $g_{7/2}$. In addition, states of more complex character are expected due to the excitation of nucleons from the Ca^{40} core.[1] These states should be bound in the case of Ca^{41} for which the separation energy of a neutron is 8.37 Mev, while for Sc^{41} they are expected to be unbound since the separation energy for a proton is only 1.63 Mev.[2] Whether or not the difference in the binding of the states has an important effect on their ordering is unclear.

The experimental evidence supporting the existence of the single-particle states is rather scant and comes for the most part from the $Ca^{40}(d,p)Ca^{41}$ reaction.[3] By application of stripping theory to the angular distributions of the resolved proton groups, it is possible to assign the orbital angular momenta of the captured neutrons and by a comparison of the relative cross sections at the maxima of the angular distributions, a distinction can be made between states of mainly single-particle character and those of more complex character. On this basis, the $p_{3/2}$ and $p_{1/2}$ levels have been tentatively assigned at energies of 1.947 and 3.950 Mev, respectively.[4] Seven other levels between 2 and 4 Mev have been assigned l values ($l \leq 2$), but none of these are formed with sufficient intensity to suggest possible single-particle character. In addition, thirteen states in this interval have been located which show no stripping maxima. The data available on the states of Sc^{41} are less complete. States formed by $l=1$ protons in the $Ca^{40}(d,n)Sc^{41}$ reaction have been reported at excitation energies of 1.86 and 2.07 Mev,[5] one of which by analogy with Ca^{41} is probably the $p_{3/2}$ single-particle state. Levels at 2.25 and 3.44 Mev are known from (p,γ) measurements,[6] and at energies above 6 Mev a number of states have been located by the study of the $Ca^{40}(p,p'e^{\pm})Ca^{40}$ reaction.[7]

In the work reported here, additions to the body of information available on Sc^{41} have been made by studying the elastic scattering of protons from Ca^{40}.[8] As is well known, when elastic scattering measurements are made with good resolution, one is able not only to locate excited states of the compound system but also to make spin and parity assignments for the states by an analysis of the resonance shapes. This analysis is much simplified when, as in the case at hand, the target nucleus has zero spin.[9] Another feature of interest in this case results from the low excitation energy with which Sc^{41} can be formed, which enables one to examine much of the energy interval relevant to shell-model considerations.

The details of the experimental method and the complete analysis of the results will be published elsewhere.[10] To summarize briefly the essential points here, the measurements were carried out at bombarding energies between 1.2 and 5.5 Mev, corresponding to excitation energies in Sc^{41} between 2.8 and 7 Mev. The region below an excitation energy of about 2.8 Mev was inaccessible because of the weak penetration of the Coulomb barrier by low-energy protons. The protons, scattered from thin (~2 kev) Ca targets evaporated onto 100-$\mu g/cm^2$ thick carbon foils, were detected at 90, 125, and 150 degrees with respect to the beam direction by a CsI crystal spectrometer which satisfactorily resolved the elastic groups from calcium and carbon. The shapes of the resonances were analyzed by application of dispersion theory, aided by the use of an electronic computer.[11] Essentially unambiguous assignments of the l values of the protons forming forty-two states were made as a result of this analysis, and it was possible to make j-value assignments to about twenty states with considerable certainty. In addition to $l(j)$ and π, the widths of the levels were also obtained from the analysis after suitable corrections were made for the effects of finite target thickness and energy spread of the beam. The Γ's so obtained needed no correction for effects of competing reactions in this case since the (p,p) process is the only particle reaction which occurs until a bombarding energy of about 5 Mev is reached, when the (p,p') reaction develops. The (p,γ) partial width is assumed negligible. From knowledge of the Γ and the l value of a state, the reduced width γ^2, given by $\gamma^2=\Gamma/2kRP_l$, is readily obtained, where P_l is the penetrability of a proton having angular momentum l, k is its wave number, and R is the nuclear radius which in this case was taken to be 5.13 fermis. The magnitude of this quantity relative to the Wigner limit for this quantity gives a measure of the single-particle character of the state involved. In Fig. 1 the values of γ^2/γ_w^2 for states of given l (or j) are plotted as a function of the excitation energy.

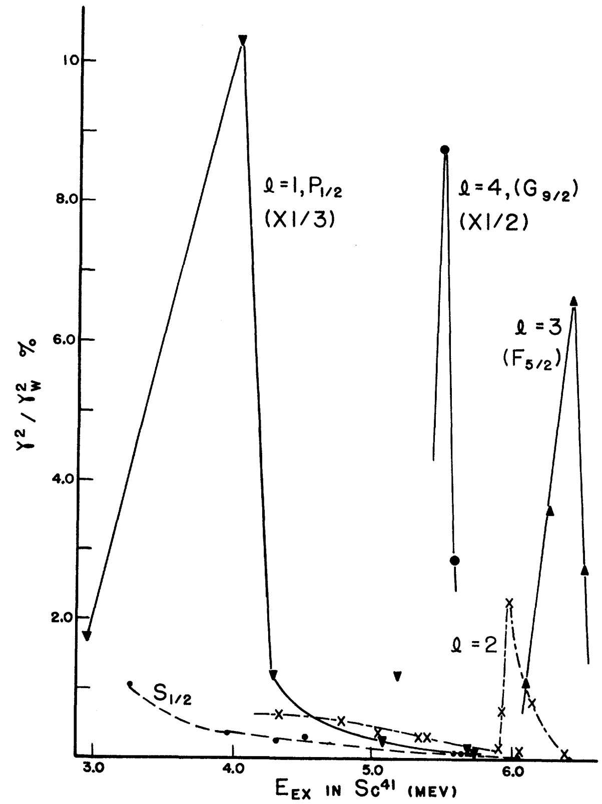

FIG. 1. The reduced widths of the states observed in elastic scattering of protons, expressed as a fraction of the Wigner single-particle limit, are shown as a function of the excitation energy in Sc^{41}. The lines connect the data points for states formed by protons of a fixed l value.

The results shown in Fig. 1 display several noteworthy features:

(1) The marked peaking of γ^2/γ_w^2 for different $l(j)$ values suggests the influence at these energies of the single-particle states expected from the shell model although these states appear in a somewhat different order than predicted.[1] The discrepancy of order is not surprising and calls for the choice of a more suitable potential for determining the positions of these states. It might also be remarked that s states, for which the efficiency of detection is greatest due to the favorable penetrability factors, are relatively few and that their reduced widths are significantly smaller than for those states expected from the shell model. This would seem to imply that the s states in this region of excitation involve a complex mode of excitation of the Ca^{40} core.

(2) While there are too few states contributing to make a strong argument, it appears that the envelope of the reduced widths of states formed by protons of a given $l(j)$ value shows a character which is illustrative at relatively low energies of excitation of the giant resonances discussed in the complex potential model[12] and in a more detailed fashion in the intermediate-coupling model of Lane, Thomas, and Wigner.[13] The occurrence of these maxima may also be viewed as supporting the interpretation of the strong maxima found in

Table I. Experimental single-particle level spacings.

Levels	ΔE (Mev) (present work)	ΔE (Mev) (reference 3)
$1f_{5/2}-1f_{7/2}$	6.4	$\geqslant 4$
$2p_{1/2}-2p_{3/2}$	2.2	~ 1.8
$2p_{3/2}-1f_{5/2}$	4.5	$\geqslant 1$
$1g_{9/2}-2p_{1/2}$	1.5	...
$2d_{5/2}-2p_{1/2}$	1.9	...

the spectra of protons from (d,p) reactions for this region of nuclei as due to the influence of single-particle states on the level structure.[14]

(3) If one assumes that the groups of states according to $l\,(j)$ value are in fact identifiable with the appropriate single-particle states, then the mean energy spacings of these states are of interest in connection with theories of the origin and magnitude of the spin-orbit force. The spacings observed in our measurements are summarized in Table I, and for comparison previous estimates of these spacings are included when available.

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*Now at Florida State University, Tallahassee, Florida.

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ENERGY SPECTRUM OF PHOTONEUTRONS FROM OXYGEN

Carmelo Milone
Istituto di Fisica dell' Universita, Centro Siciliano di Fisica Nucleare, Catania, Italia
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The energy spectrum of the photoneutrons from oxygen has been studied by irradiation of a water target with a 31-Mev collimated bremsstrahlung beam from the Brown Boveri betatron of Torino University.

Photoneutrons emitted at about 90° with the γ-ray beam have been recorded by means of the proton recoil tracks in Ilford L_4 plates 400 μ thick. A water wall 60 cm thick screened the plates against the spurious neutrons coming directly from the betatron, as in a previous work.[1]

Plates were scanned and proton recoil tracks were selected following the method used previously.[1]

The neutron spectrum is deduced from the proton recoil spectrum taking into account the cross section for (n,p) collisions in the hydrogen of the emulsion. The relation $E_n=E_p/\cos^2\theta$ was introduced only for $\theta>10°$. Small corrections are due to the probability of escape of the tracks from the emulsion[2] and to the absorption and scattering of neutrons in the target. The experimental energy spectrum is given in Fig. 1(a).

Under the restrictive assumption that only the direct $O(\gamma,n)$ process is effective and that the residual O^{15} nucleus is left in the ground state, the expected neutron spectrum may easily be inferred from the $O(\gamma,n)$ cross section,[3] taking