Excited-Core Model in Al^{27} and Inelastic Scattering of 14.2-MeV Neutrons*

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Differential cross sections for 14.2-MeV neutron inelastic scattering to the first levels in Al^{27} have been measured at forward angles using a time-of-flight spectrometer. The experimental values agree with the predictions of the excited-core model; mixing between the ground state and the $\frac{5}{2}^+$ excited state must be allowed for, the square of the mixing parameter being $A^2=0.82\pm0.07$.

I. INTRODUCTION

RECENTLY some features of nuclear-particle inelastic scattering on light nuclei have been interpreted[1–4] using the excited-core model.[5,6] Actually this has been done comparing the results obtained for a collective excited state in an even-even nucleus with the results obtained for the corresponding level multiplet in the neighboring odd nucleus. In the region of light nuclei Al^{27} and Si^{28} lend themselves to such an interpretation; it is in fact possible to assume that the quintet of levels up to 3 MeV in Al^{27} is due to the coupling of the $1d\ \frac{5}{2}^+$ proton hole to the 1.78-MeV 2^+ core level in Si^{28}. Measurements performed with charged particles[1–3] showed approximate agreement with the model, while for neutrons used as incident particles it was not possible to test this model, data being available[7,8] only on Si^{28}. This has led us to perform an experiment on inelastic scattering of 14.2-MeV neutrons on Al^{27}, which we report in this paper.

II. EXPERIMENTAL METHOD

By using a time-of-flight spectrometer[9,10] we measured the scattering of 14.2-MeV neutrons on Al^{27} leaving the nucleus, respectively, in the $\frac{1}{2}^+$ 0.84-MeV, $\frac{3}{2}^+$ 1.01-MeV, $\frac{7}{2}^+$ 2.21-MeV, $\frac{5}{2}^+$ 2.73-MeV, $\frac{9}{2}^+$ 2.98-3.00-MeV excited states. The apparatus had a time resolution of 1.6 nsec full-width at half-maximum giving a 4% energy resolution for 14.2-MeV neutrons for the 4-m flight path used. The experimental arrangement was the same as described in a previous paper[4]; the aluminum target had the form of a disc 2 cm thick and it intercepted completely the neutron cone defined by the associated α particle. While measurements were carried out the target was automatically brought into or away from the neutron cone, thus allowing background subtraction. The angular distribution was measured at forward angles from 25° to 90° in seven steps; at each point the counting lasted more than 100 h.

III. RESULTS

An example of the time-of-flight spectrum measured at 40° is given in Fig. 1, in which the arrows indicate the position of groups of neutrons as calculated from the known level structure in Al^{27}. The peaks due to levels 0.84 and 1.01 MeV are unresolved, those due to levels 2.21, 2.73, and 3.00 MeV are not fully resolved, the resolution of the spectrometer being about 0.45 MeV in this energy region. Nevertheless, it is possible to evaluate the contribution due to each of these three levels if the exact position and the instrumental shape of the peaks are known, using for instance a method similar to that described by Carnahan.[11]

The data thus obtained were corrected for neutron absorption in the target and normalized to known[7,12] cross sections for elastic scattering on C^{12}. Fractional standard errors computed using data from partial measurements turned out to be about 25%, except that for the $\frac{5}{2}^+$ level it was about 80% owing to the overlapping with the $\frac{7}{2}^+$ and $\frac{9}{2}^+$ peaks. Results are reported in Table I and angular distributions are depicted in Figs. 2 and 3.

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[1] H. Niewodniczański, J. Nurzyńsky, A. Strzałowski, J. Wilczyńsky, J. R. Rook, and P. E. Hodgson, Nucl. Phys. **55**, 386 (1964).
[2] J. C. Jacmart, M. Liu, R. A. Ricci, M. Riou, and C. Ruhla, Phys. Letters **8**, 273 (1964).
[3] J. Kokame, K. Fukunaga, and H. Nakamura, Phys. Letters **14**, 234 (1965).
[4] G. C. Bonazzola and E. Chiavassa, Nucl. Phys. **68**, 369 (1965).
[5] R. D. Lawson and J. L. Uretsky, Phys. Rev. **108**, 130 (1957).
[6] A. de-Shalit, Phys. Rev. **122**, 1530 (1961).
[7] R. L. Clarke and W. G. Cross, Nucl. Phys. **53**, 177 (1964).
[8] P. W. Martin, D. T. Stewart, and J. Martin, Nucl. Phys. **61**, 524 (1965).
[9] G. C. Bonazzola and E. Chiavassa, Nucl. Instr. Methods **27**, 41 (1964).
[10] G. C. Bonazzola and E. Chiavassa, Atti Accad. Sci. Torino: Classe Sci. Fis. Mat. Nat. **98**, 1 (1964).
[11] C. L. Carnahan, Nucl. Instr. Methods **30**, 165 (1964).
[12] R. Bouchez, J. Duclos, and P. Perrin, Nucl. Phys. **43**, 628 (1963).

TABLE I. Differential elastic and inelastic cross section for 14.2-MeV neutrons on Al^{27}.

$\theta_{\text{c.m.}}$	$d\sigma/d\omega$ (mb/sr) $Q=0$	$d\sigma/d\omega$ (mb/sr) $Q=-0.84$ and -1.01 MeV	$d\sigma/d\omega$ (mb/sr) $Q=-2.21$ MeV	$d\sigma/d\omega$ (mb/sr) $Q=-2.73$ MeV	$d\sigma/d\omega$ (mb/sr) $Q=-3.00$ MeV
26°	290±29	4.4±1.3	7.7±1.7	0.8±0.6	7.7±1.9
39°	18±2	4.8±0.3	4.4±1.0	2.3±1.8	5.5±1.3
47°	31±3	3.1±0.5	5.6±1.4	0.6±0.5	2.9±0.6
57°	63±1	3.9±0.8	4.5±0.8	1.4±1.1	5.0±1.5
68°	40±2	2.2±0.7	2.8±1.0	0.6±0.4	1.7±0.5
76°30′	25±4	1.4±0.5	1.3±0.5	0.4±0.3	2.0±0.7
89°30′	15±2	1.9±0.7	2.3±0.8	0.7±0.5	1.7±0.6

IV. DISCUSSION

From Fig. 2 it appears that our results for elastic scattering are in agreement with previous calculations[13] for Al^{27}. This angular distribution is also in good agreement with data given in Refs. 7 and 8 for Si^{28} and this fact can be considered as an argument in favour of the excited-core model even though such behavior is equally well predicted by the optical model. Stronger arguments may be found by analyzing the inelastic-scattering results reported in Figs. 3 and 4. For instance, it is important that the four angular distributions exhibit a similar trend, and even more convincing is the identity, within errors, of the differential cross section obtained by summing the values for the quintet of levels in Al^{27} and the differential cross section for the 2^+ level in Si^{28}. Finally we find verified another peculiar feature of the excited-core model, i.e., the $(2J+1)$ rule[1,3,4] for the scattering intensity from each level in Al^{27}. This can be seen in Table II where we report the values of experimental differential cross section for Al^{27} integrated from 30° to 90° compared with the cross sections calculated using for Si^{28} the value ob-

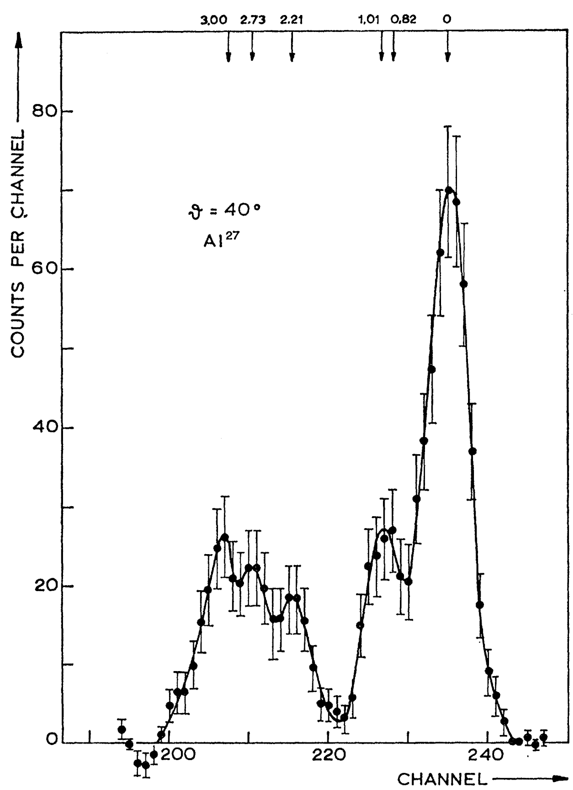

FIG. 1. Time-of-flight spectrum of 14.2-MeV neutrons scattered from Al^{27}. Arrows indicate the expected position of groups of neutrons.

TABLE II. Experimental and calculated integrated cross sections for inelastic scattering of 14.2-MeV neutrons to the first levels in Al^{27} and Si^{28}.

	J	$\int_{\pi/6}^{\pi/2} (d\sigma/d\omega)_{Al^{27}} d\omega$	$\frac{1}{30}(2J+1)\int_{\pi/6}^{\pi/2} (d\sigma/d\omega)_{Si^{28}} d\omega$
Al^{27}	$\frac{1}{2}^+$, $\frac{3}{2}^+$	15.9±1.4	12.6±1.0
	$\frac{7}{2}^+$	17.6±2.0	16.8±1.4
	$\frac{5}{2}^+$	5.7±2.3	12.6±1.0
	$\frac{9}{2}^+$	18.4±2.4	20.9±1.7
Si^{28}	2^+	62.8±5.1	

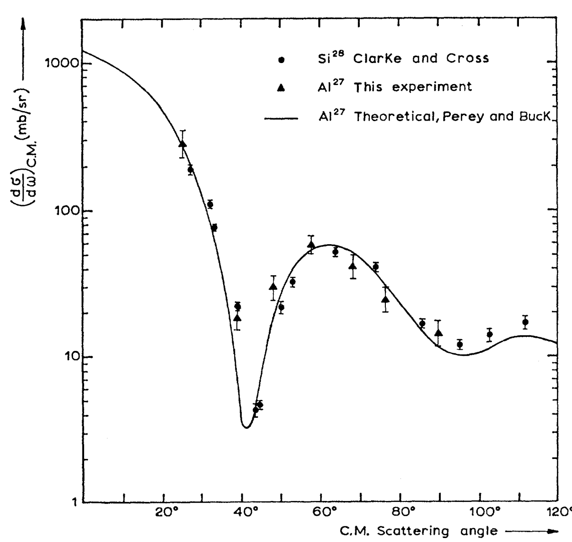

FIG. 2. Differential cross section for elastic scattering of 14.2-MeV neutrons from Al^{27} and Si^{28}.

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[13] F. Perey and B. Buck, Nucl. Phys. 32, 353 (1962).

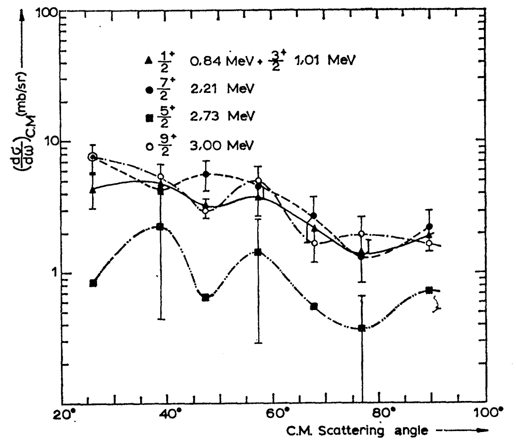

FIG. 3. Differential cross section for inelastic scattering to the first excited states in Al^{27}.

tained integrating, over the same angle interval, the differential cross section given in Ref. 7.

A similar comparison was made by Niewodniczańsky[1] for inelastic scattering of 12.8-MeV deuterons to the first five levels in Al^{27}. In Table III we report the ratio

TABLE III. Ratio between experimental and calculated inelastic-scattering cross sections in Al^{27} for neutron and deuteron experiments.

J	$\frac{1}{2}^+ + \frac{3}{2}^+$	$\frac{7}{2}^+$	$\frac{5}{2}^+$	$\frac{9}{2}^+$
$(\sigma_{expt}/\sigma_{calc})$, neutrons	1.26±0.15	1.05±0.15	0.45±0.18	0.88±0.13
$(\sigma_{expt}/\sigma_{calc})$, deuterons	1.11±0.25	0.75±0.18	0.39±0.09	0.72±0.17

of the integrated experimental cross sections calculated by applying the $2J+1$ rule for the deuteron and neutron experiments. There can be seen in this table a reasonable agreement between theory and experiment for all but the $\frac{5}{2}^+$ level. This irregularity is confirmed in both experiments; in Ref. 1 this is accounted for by allowing a mixing between the $\frac{5}{2}^+$ excited state and the ground state which has the same spin and parity. From our data we find for the mixing parameter[14,15] a value $A^2=0.82\pm0.07$ which is in agreement with the value $A^2=0.72\pm0.03$ reported from the deuteron experiment. In Ref. 1 some doubts are raised against the

[14] A. Braunstein and A. de-Shalit, Phys. Letters **1**, 264 (1962).
[15] J. Vervier, Nuovo Cimento **28**, 1412 (1963).

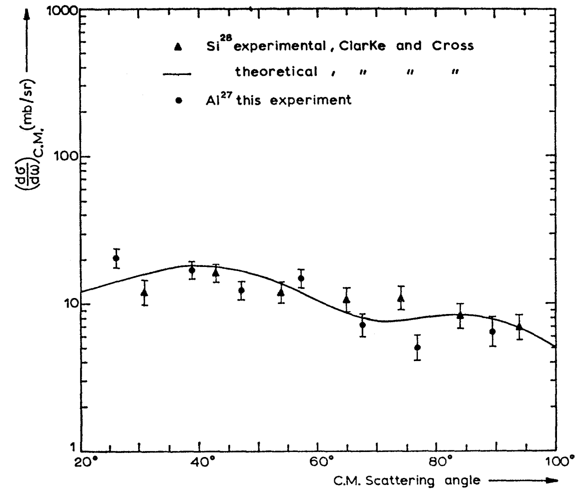

FIG. 4. Comparison between the differential cross section for 14.1-MeV neutron inelastic scattering to the 1.78-MeV 2^+ level in Si^{28} and the sum of the inelastic-scattering differential cross sections of 14.2-MeV neutrons to the first five levels in Al^{27}.

assignment $\frac{9}{2}^+$ to either of the members of the 3.0-MeV doublet, the intensity of the deuteron scattering to these levels being lower than expected. For neutron scattering we find a cross section more consistent with theoretical predictions so that we can sustain the $\frac{9}{2}^+$ assignment.

Finally we will recall that recently Kokame *et al.*[3] made a comparison between measurements[16,17] on (α,α') reaction on Si^{28} and Al^{27}. In this case the predictions of the excited-core model are well confirmed as to similarity of angular distributions and statistical weight of the intensity of transitions to the different levels, while Kokame's differential cross section for the 1.28-MeV level in Si^{28} is 30% higher than the sum of the integrated cross sections for the quintet of states in Al^{27} as given by Ref. 16. From the analysis of the reported measurements we conclude that any nuclear-particle scattering experiment on Al^{27} can be well described by the excited-core model.

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[16] J. Kokame, K. Fukunaga, N. Inoue, and H. Nakamura, Phys. Letters **8**, 342 (1964).
[17] I. Kumabe, H. Ogata, N. Inoue, Y. Okuma, and J. Muto, J. Phys. Soc. Japan **19**, 147 (1964).