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## Sc<sup>45</sup> AND THE EXCITED CORE MODEL

H. J. ERRAMUSPE

Synchrocyclotron Laboratory, Comisión Nacional de Energía Atómica

BUENOS AIRES, ARGENTINA (\*)

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**Abstract:** The validity of the excited core model in the case of Sc<sup>45</sup> is studied by using elastic and inelastic proton scattering from Sc<sup>45</sup> and Ti<sup>46</sup>.

It is shown that the corresponding multiplet can be interpreted as an interaction of a hole in the  $1f_{7/2}$  shell with the core of Ti<sup>46</sup>. From the five members of the multiplet four were certainly identified. The fifth is only found with some probability.

Spins and parities were tentatively assigned and intensity rule, center of gravity theorem and shapes of the angular distributions were verified.

1. INTRODUCTION.— It is a very well known fact that it has been possible in the past to interpret many properties of the low-lying levels of F<sup>19</sup> with the aid of different descriptions of nuclear structure (ref. 1) and references cited therein).

A similar situation develops in the  $1f_{7/2}$  shell for the Sc nuclei, in whose case the doubly-closed Ca<sup>40</sup> nucleus acts as the corresponding core. In this region more severe tests can be carried out upon the various models that successfully explained different features of the F<sup>19</sup> spectrum, since the spectra of the many odd-mass isotope nuclei of Sc are now accessible due to the use of more refined experimental techniques<sup>1)</sup>.

This circumstance has determined a great deal of experimental and theoretical work in order to obtain the spins and parities of the corresponding nuclear states, to make these tests possible.

It has been the purpose of this work to continue the studies undertaken in this region, by studying elastic and inelastic proton scattering processes from the nuclei of Sc<sup>45</sup> and Ti<sup>46</sup>, in order to verify the possible validity of the excited core model for the nucleus of Sc<sup>45</sup>.

According to this model, proposed by Lawson and Uretzky<sup>2)</sup> and extended later by de-Shalit<sup>3)</sup>, it is assumed that an odd-nucleus is formed by the nearest even-even nucleus acting as a core plus a nucleon in its lowest energy state. If the particle excitation energy is large when compared with the lowest excitation energy of the even-even core, it

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is possible to imagine the lowest excitations of the odd-nucleus be represented by the interaction of the odd-nucleon (or hole) that remains in its lowest orbit with the core excited to its first state. The core-particle interaction removes the  $J$  degeneracy, leaving only the obvious  $M$  degeneracy.

It has been pointed out in different opportunities, on the other hand, that the identification of the different members of a core multiplet in an odd-even nucleus may become quite difficult. This situation mainly arises when the information on excited levels, whose spins are rather close one to the other and have the same parities, is obtained via electromagnetic transitions studies. If, instead, the study is carried out by using nuclear reactions, the conditions are entirely different. This situation stem from the fact that the members of the core multiplet share the excitation of the first  $2^+$  level in the neighboring even-even nucleus, which is usually strongly excited (see ref. <sup>4</sup>) for the excitation of the first level of  $Ti^{46}$ ). This circumstance renders the identification much easier due to the enhancement of the corresponding cross sections.

2. EXPERIMENTAL METHODS.— The experiment was performed using the external proton beam facilities of the Columbia University Pupin 36 in. cyclotron. The experimental arrangement has been described previously<sup>5</sup>). Particle detection was made with the use of Si (Li drifted) solid state detectors. Resolutions of the order of 100 keV were obtained. The angular distributions were measured with a scattering chamber described elsewhere <sup>6</sup>).

The energy spread of the beam after collimation was measured and an approximate value of 60 keV was obtained.

The whole system was optically aligned and check with the aid of a kinematic method <sup>7</sup>).

Two multichannel analyzers were available and used according to the description given elsewhere <sup>5</sup>). After the dead time checks were carried out, one of the multichannel was used under different electronic conditions, so as to change the number of keV per channel, in order to use the full resolution of the available detectors. Constants ranging from 18 to 40 keV per channel were used. The constant relative to the other multichannel was kept fixed for kinematic studies.

Detector collimators were used, defining a solid angle of the order of  $10^{-1}$  and a semiangle at the centre of  $22^\circ$ , avoiding in this way corrections due to finite aperture.

The thicknesses of the targets were measured by the gravimetric technique with the aid of a microbalance and a microscope. They were obtained from Oak Ridge National Laboratory. Targets of 0.90 and 3.90 mg/cm<sup>2</sup> of  $Sc^{45}$ , 100 % pure, were used. The  $Ti^{46}$  target was obtained with only 77.1 % purity. The relative cross sections were determined by using targets of  $Ti^{48}$ , 99.36 % pure, and an appropriate system of equations<sup>4)</sup>. The uniformity of the target thickness was investigated in the manner which has been previously described<sup>4,5)</sup>. It was found better than 1 %.

Total charge collection verifications were made through multiple scattering calculations and experimental tests<sup>5)</sup>. The root mean square angle of multiple scattering turned out to be 23' for the thickest target. Therefore, security factors of the order of 10 and 15 were obtained. The experimental test with an auxiliary target and for target-in and target-out positions of the main target gave an upper limit of 0.29 % of beam lost, entirely within the experimental error. A monitor, to check the reproducibility of the positions of the targets, was also used.

An oxygen impurity was found in the  $Sc^{45}$  target. Its thickness was evaluated as  $23 \pm 2 \mu\text{g}/\text{cm}^2$ , taking advantage of the kinematic shift at backward angles and the previous knowledge of its differential cross-section at this energy<sup>7)</sup>.

The  $Sc^{45}$  nucleus is known to have many low-lying levels, whose energy values have been found by using nucleon scattering and coulomb excitation methods. In this study use is made of the energy statements given by Buechner and Mazari<sup>8)</sup> whose investigations are the most extensive and include almost all the levels found in other investigations. We enumerate the levels here according to this work. More recently, however, a new level at  $13 \pm 1 \text{ keV}$  has been found<sup>4,9)</sup>. The spin assignment is  $3/2^+$  (a hole in the  $1 d_{3/2}$  shell).

Spectra at 80°, 90° and 150° (laboratory angles) are shown in figs. 1, 2 and 3, respectively. It can be seen there the enhancement of the cross sections corresponding to the levels at 0.376 MeV (level 1), 0.719 MeV (level 3), 1.236 MeV (level 7) and 1.661 MeV (level 12). The doublet at 1.408-1.433 MeV (levels 9 and 10) appears well resolved from the other peaks in the spectra at 80° and 90°. The oxygen contamination can also be seen in these spectra. In the spectrum at 150° the peak belonging to the doublet is not resolved and appears as a bump under the peak corresponding to the seventh level.

Statistical, geometric, charge collection, dead time, background and target thickness errors were taken into consideration<sup>5)</sup>. Target and ob-

servation angle errors can be estimated to be less than  $\pm 0.2^\circ$ . The background errors were obtained by taking extreme background subtraction curves averaging and taking as error the deviation from the average value.

3. RESULTS AND DISCUSSION.— If the experiment is carried out at an energy high enough for the nuclear interactions to play an important role, the excited core model predicts that the angular momentum transferred  $\Delta l$  during the inelastic scattering equals the spin  $J_c$  of the excited core. Since the form of the angular distributions are sensitive to this value, a comparison of forms allows a first investigation about the multiplet components.

As it was mentioned above, according to this model the multiplet members share the excitation of the core, of a collective character, the core being approximately represented by the neighboring even-even nucleus. If  $J$  stands for the spins of the members of the core multiplet and  $\sigma_c$  is the cross section corresponding to the first  $2^+$  level of the near even-even nucleus, the intensities of each member of the multiplet, being proportional to the  $M$  degeneracy, *i. e.*, to  $(2J + 1)$  are

$$\sigma_J = \frac{(2J + 1)}{\sum_J (2J + 1)} \sigma_c = \frac{(2J + 1)}{(2J_o + 1)(2J_c + 1)} \sigma_c \quad (1)$$

where  $J_o$  is the ground-state spin of the odd-even nucleus.

Naturally, the sum gives the cross section corresponding to the core. This is known as the intensity rule.

Moreover, if there is no monopole-monopole term in the interaction and the near even-even nucleus is a good representation of the core of the odd-even nucleus, the center of gravity theorem states

$$\sum_J (2J + 1) E_J = (2J_c + 1)(2J_o + 1) E_c \quad (2)$$

where the  $E$ 's are the corresponding energies.

Finally, the elastic scattering for both nuclei must show similar features.

If this model works in the case of  $Sc^{45}$ , the excited levels of this nucleus, of a collective character, can be interpreted as a coupling of a hole in the  $1f_{7/2}$  shell to the core of the even-even nucleus of  $Ti^{46}$ . Since the ground-state spin of  $Sc^{45}$  is  $7/2^-$ , the model predicts a quintet of levels  $3/2^-$ ,  $5/2^-$ ,  $7/2^-$ ,  $9/2^-$  and  $11/2^-$ .

In fig. 4 the inelastic angular distributions are shown. The upper curve corresponds to the first excited level ( $2^+$ ) of  $Ti^{46}$  ( $Q = -0.885$  MeV). The points of the other curves represent the differential cross sections of the levels at 0.376, 0.719, 1.236 and 1.661 MeV of  $Sc^{45}$ . The angular distribution for the unresolved 1.408 – 1.433 MeV doublet is also shown. The full line is the experimental curve corresponding to  $Ti^{46}$  which is also drawn on the differential cross sections of  $Sc^{45}$  with comparative purposes.

The similarity, as predicted by the model, is accomplished.

It is not sure that the doublet belongs to the multiplet. It is seen that has not been possible to follow the whole angular distribution.

In this figure the double circles correspond to reiterations and the triangles to measurements taken at different times, in completely independent runs. Bars represent errors. The large errors at forward angles (see also table 2) are due to the increasing background subtraction uncertainties, since Rutherford scattering represents the largest part of the interaction, as illustrated in fig. 4 of ref <sup>4</sup>).

Tables 1 and 2 show the values of the absolute differential elastic and inelastic cross sections respectively, with their errors. In the first case the ratio to the Rutherford cross section is also shown.

The elastic angular distribution similarity is shown in fig. 5. It can be seen there that the diffraction features are quite similar in both cases, with a first minimum near  $85^\circ$  and a second one around  $135^\circ$ . There is also a bump in the angular distribution around  $50^\circ$  with a first maximum at  $105^\circ$  in both cases.

To make a tentative spin assignment the intensity rule plays an important role. By using the cross sections corresponding to the four levels whose angular distributions have been followed in the whole angular range, a tentative spin assignment has been done and results compared with the calculated cross sections according to eq. (1). Results are shown in table 3.

As it can be observed, there is a very good agreement for the levels at 0.719 and 1.236 MeV. The accordance for the level at 0.376 MeV is also rather good. Although the spins can be interchanged between the 0.376 and 1.661 MeV levels without substantially affecting the agreement, this possibility must be rejected because 94 % of the gamma transitions lead to the  $3/2^+$  state at 13 keV (see ref. 10).

To test the intensity rule with regard to the sum of the cross sections, it is convenient to take angles at  $130^\circ$  and  $140^\circ$ , because for these angles there is no oxygen contamination due to the kinematic shift and, therefore, the spectra are much cleaner. It is obtained 83 % and

80 % of the calculated values, respectively. These agreements are very acceptable if it is taken into account that the cross sections errors are of the order of 15 %.

The intensity of the doublet is smaller than calculated as if belonging to the quintet. At  $90^\circ$ , the best resolution for this peak, the cross section is  $0.23 \pm 0.05$  mb/sr against  $0.77 \pm 0.04$  mb/sr as calculated value. This low value, however, could be expected on very general grounds, because this level has the same spin and parity as the ground-state. There is then an admixture between the core and the ground-state wave functions, due to residual interactions. The cross sections of the excited state is always reduced due to these admixtures, reappearing the missing transition strength in the elastic scattering<sup>11)</sup>. This coupling also repels the  $7/2^-$  excited state to a higher energy<sup>12)</sup>. Owing to the above mentioned reasons it has been assumed that the missing member of the quintet would be the  $7/2^-$  state, in case the doublet at 1.408–1.433 MeV did not belong to the multiplet. It must be pointed out, also, that the 1.661 MeV level has only a value from 40 % to 50 % of the calculated one. This may be indicative of a coupling with some higher  $9/2^-$  level which shares the transition strength.

The first spin assignment to the 0.376 MeV level was  $5/2^-$  (see ref. 13)). This assignment was based on considerations about systematics for  $\log ft$  of the corresponding  $\beta$  decay, although it was recognized then that the systematics was very poor.

In the work of ref. 14) spin assignments of other levels were made on the basis of an investigation of the gamma-ray decay of the  $C^{44}(p, \gamma)Sc^{45}$  1.660 MeV resonance, corresponding to the level at 8.51 MeV in  $Sc^{45}$ . The spin assignment for the first level was taken from ref. 13). These values, however, must be revised because at that time it was not known the existence of the  $3/2^+$  level at 13 keV in  $Sc^{45}$ , what invalidates the analysis that was carried out.

More recently, angular correlation studies of the de-excitation gamma rays following the coulomb excitation of the 0.376 MeV level of  $Sc^{45}$  pointed out to a spin and parity  $5/2^-$  rather than  $3/2^-$  (see ref. 15)).

Schwartz and Alford<sup>16)</sup>, however, founded on stripping reaction studies of the type  $(He^3, d)$  and the good agreement obtained by using DWBA calculations with an angular momentum transferred  $l = 1$ , assigned spin and parity  $3/2^-$  to this level. In the corresponding correlations studies, nevertheless, either assignment would be consistent with the measured values of the angular correlation coefficient  $A_2^2$ .

From table 3 it can be seen that the calculated cross sections for spin  $3/2$  could be assigned to the 0.376 MeV level. The interchange of

spins between the 0.376 and 0.719  $MeV$  levels, however, would result in a worsening of the overall agreement, since the spin  $9/2$  can not be assigned to the 0.719  $MeV$  level, according to the results of the study of ref. <sup>14)</sup>. Therefore, the spin assignments of table 3 seems to be the best choice.

Moreover, according to this model the reduced  $E2$  transition probabilities from the different members of the multiplet to the ground state should be equal and will also be the same as the  $B(E2 : 2 \rightarrow 0)$  for transitions in the neighboring even-even nucleus, if the core state in the odd-even nucleus is identical with the corresponding state in the even-even nucleus <sup>3)</sup>.

On the other hand, the collective properties of these two levels seems to find a confirmation through their excitations when  $Sc^{45}$  is bombarded with heavy ions <sup>19)</sup>. In the study of ref. <sup>16)</sup> the reduced transitions probabilities  $B(E2)\uparrow$  were calculated assuming that a cascade transition does not take place from the 0.719  $MeV$  level. Dubois *et. al* <sup>17)</sup>, however, state that no branching of the third state could be detected.

D. G. Alkhazov *et. al* <sup>16)</sup> state the following values for the reduced transitions probabilities

$$0.376 \text{ MeV level: } B(E2)\uparrow = 0.0093 e^2 \cdot 10^{-48} \text{ cm}^4 \quad (3)$$

$$0.719 \text{ MeV level: } B(E2)\uparrow = 0.0045 e^2 \cdot 10^{-48} \text{ cm}^4 \quad (4)$$

In the study of ref <sup>4)</sup> it was obtained for  $B(E2 : 0 \rightarrow 2)$  for the nucleus of  $Ti^{46}$

$$B(E2)\uparrow = 0.0738 e^2 \cdot 10^{-48} \text{ cm}^4 \quad (5)$$

This value was obtained for the strong coupling approximation <sup>18)</sup>. Nevertheless, it must be almost equal to the value obtained via coulomb excitation by Stelson and McGowan <sup>19)</sup>, although this is not reported, since the nuclear deformation parameters were approximately the same in both cases, this parameter being extracted in the latter study through the strong coupling approximation, too.

By applying the relationship

$$B(\lambda : J_f \rightarrow J_i) = \frac{2J_i + 1}{2J_f + 1} B(\lambda : J_i \rightarrow J_f) \quad (\text{see ref. } ^{20)})$$

where  $\lambda$  is the radiation multipolarity and  $J_i, J_f$  stand for the spins of the initial and final states, respectively, it is obtained

$$B(E2: 3/2 \rightarrow 7/2) = 2 B(E2: 7/2 \rightarrow 3/2) \quad (6)$$

$$B(E2: 5/2 \rightarrow 7/2) = 1.33 B(E2: 7/2 \rightarrow 5/2) \quad (7)$$

With the aid of eqs. (6) and (7) it is possible to find  $B(E2)\downarrow$  for the levels in question for different spin assignments.

*0.376 MeV level of Sc<sup>45</sup>*

$$\text{Spin } 3/2 : B(E2)\downarrow = 0.0186 \text{ in units of } e^2 \cdot 10^{-48} \text{ cm}^4$$

$$\text{Spin } 5/2 : B(E2)\downarrow = 0.0124$$

*0.719 Mev level of Sc<sup>45</sup>*

$$\text{Spin } 3/2 : B(E2)\downarrow = 0.0090$$

$$\text{Spin } 5/2 : B(E2)\downarrow = 0.0060$$

*0.885 Mev level (2<sup>+</sup>) of Ti<sup>46</sup>*

$$B(E2)\downarrow = \frac{1}{5} 0.0738 = 0.0148$$

If the last value reported by Temmer and Heydenburg<sup>21)</sup> is used.  $B(E2)\uparrow = 0.056 e^2 \cdot 10^{-48} \text{ cm}^4$ , we obtain

$$B(E2)\downarrow = 0.0112$$

Through this study it is observed that the spin assignment of table 3 is favored, although it can not be considered conclusive in view of the strong presumption obtained via the stripping reaction  $Ca^{44}(He^3, d)Sc^{45}$ .

On the other hand, the agreement among the reduced transition probabilities values lends support to the validity of the model in this case.

Finally, the verification of the centre of gravity theorem can be made. From eq. (2) and the spin assignment of table 3, it is obtained 1.196 MeV for the energy of the centre of gravity. This value must be compared with the energy of the first excited level of  $Ti^{46}$ . The difference amounts 0.311 MeV, which is a reasonable result taking into consideration the circumstances that can make the theorem to fail (monopole-monopole interaction between the odd particle or hole and the core, different excitations energies of the odd-even nucleus core and the neighboring even-even nucleus, repulsion of levels, etc.).

It is worth noting that in this case the states of a collective origin are mixed with some other states and that they do not correspond to the lowest energies.

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TABLE 1

Absolute differential elastic cross sections for  $Sc^{45}$ ;  $\psi$ : laboratory angle;  $\theta$ : centre of mass angle;  $E_p = 14.55$  MeV;  $Q = 0$

$\theta$	$\sigma(\psi)$	$\sigma(\theta)$	$\Delta\sigma$	$\epsilon\%$	$\sigma/\sigma_R$
5.11	726 $\times 10^3$	695 $\times 10^3$	$\pm 70 \times 10^3$	10.0	0.953
10.22	28.8 $\times 10^3$	27.6 $\times 10^3$	$\pm 1.5 \times 10^3$	5.6	0.604
15.3	5.09 $\times 10^3$	4.88 $\times 10^3$	$\pm 0.29 \times 10^3$	6.0	0.536
20.4	1.62 $\times 10^3$	1.55 $\times 10^3$	$\pm 0.05 \times 10^3$	3.2	0.533
25.5	737	708	$\pm 9.2$	1.3	0.587
30.6	392	377	$\pm 9.4$	2.5	0.638
35.7	214	206	$\pm 2.3$	1.1	0.634
40.8	128.7	124.4	$\pm 2.2$	1.8	0.639
45.9	94.3	91.4	$\pm 1.6$	1.8	0.734
51.0	77.3	75.2	$\pm 1.4$	1.8	0.895
56.0	62.9	61.3	$\pm 1.2$	1.9	1.037
61.1	47.7	46.7	$\pm 0.93$	2.0	1.084
66.2	31.52	30.9	$\pm 0.62$	2.0	0.951
71.2	15.81	15.58	$\pm 0.31$	2.0	0.621
81.3	3.097	3.07	$\pm 0.08$	2.5	0.192
91.3	6.24	6.24	$\pm 0.17$	2.8	0.566
101.2	11.69	11.78	$\pm 0.29$	2.5	1.460
106.2	12.35	12.50	$\pm 0.30$	2.4	1.776
111.2	11.97	12.16	$\pm 0.30$	2.5	1.958
121.1	6.77	6.92	$\pm 0.18$	2.6	1.381
131.0	2.635	2.71	$\pm 0.07$	2.6	0.645
140.8	1.992	2.06	$\pm 0.05$	2.6	0.563
150.6	3.76	3.91	$\pm 0.07$	2.3	1.188
160.4	5.50	5.74	$\pm 0.14$	2.5	1.882
167.3	5.88	6.14	$\pm 0.14$	2.2	2.081

TABLE 2

Absolute differential elastic cross sections for  $Sc^{45}$ ;  $\theta$ : centre of mass angle

$$\begin{aligned}
 Q_1 &= -0.376 \text{ MeV} & Q_{9/10} &= -1.408 \text{ MeV} \\
 Q_3 &= -0.719 \text{ MeV} & &= -1.433 \text{ MeV} \\
 Q_7 &= -1.236 \text{ MeV} & Q_{12} &= -1.661 \text{ MeV}
 \end{aligned}$$

$\theta$	$\sigma_1(\theta)$	$\sigma_3(\theta)$	$\sigma_7(\theta)$	$\sigma_{9/10}(\theta)$	$\sigma_{12}(\theta)$
o	mb/sr	mb/sr	mb/sr	mb/sr	mb/sr
30.7			$2.3 \pm 0.8$		$1.20 \pm 0.36$
35.8		$0.79 \pm 0.40$	$2.3 \pm 0.5$	$0.50 \pm 0.15$	$1.26 \pm 0.19$
				$0.41 \pm 0.12$	
40.9	$0.85 \pm 0.38$	$0.64 \pm 0.26$	$2.53 \pm 0.50$	$0.41 \pm 0.10$	$0.99 \pm 0.15$
	$0.89 \pm 0.40$	$0.83 \pm 0.33$			
45.9	$0.68 \pm 0.27$	$0.66 \pm 0.23$	$2.05 \pm 0.31$	$0.33 \pm 0.08$	$0.86 \pm 0.13$
		$0.68 \pm 0.24$	$1.75 \pm 0.26$		$0.72 \pm 0.11$
51.0	$0.69 \pm 0.24$	$0.50 \pm 0.20$	$1.70 \pm 0.26$	$0.38 \pm 0.10$	$0.63 \pm 0.10$
56.1	$0.44 \pm 0.15$	$0.55 \pm 0.19$	$1.25 \pm 0.31$	$0.27 \pm 0.08$	$0.62 \pm 0.10$
		$0.51 \pm 0.18$	$1.24 \pm 0.31$	$0.26 \pm 0.08$	$0.59 \pm 0.09$
			$1.33 \pm 0.33$		
61.2	$0.50 \pm 0.18$	$0.45 \pm 0.16$	$1.20 \pm 0.24$	$0.27 \pm 0.07$	$0.51 \pm 0.08$
	$0.44 \pm 0.15$		$1.08 \pm 0.22$		
66.2	$0.43 \pm 0.17$	$0.36 \pm 0.13$	$1.07 \pm 0.22$	$0.25 \pm 0.07$	$0.40 \pm 0.10$
	$0.39 \pm 0.16$	$0.32 \pm 0.11$	$1.27 \pm 0.25$		
71.3	$0.39 \pm 0.12$	$0.33 \pm 0.12$	$1.05 \pm 0.22$	$0.26 \pm 0.07$	$0.36 \pm 0.09$
	$0.41 \pm 0.12$	$0.35 \pm 0.12$	$0.95 \pm 0.19$	$0.31 \pm 0.08$	$0.38 \pm 0.09$
	$0.39 \pm 0.12$				
81.3	$0.41 \pm 0.06$	$0.34 \pm 0.05$	$0.94 \pm 0.19$		$0.38 \pm 0.08$
	$0.44 \pm 0.07$	$0.39 \pm 0.06$	$0.84 \pm 0.17$		$0.36 \pm 0.07$
91.3	$0.40 \pm 0.06$	$0.35 \pm 0.07$	$0.97 \pm 0.29$	$0.23 \pm 0.05$	$0.40 \pm 0.12$
	$0.42 \pm 0.06$	$0.41 \pm 0.08$	$0.97 \pm 0.29$		
101.3	$0.32 \pm 0.06$	$0.34 \pm 0.05$	$0.95 \pm 0.29$		$0.38 \pm 0.12$
111.3	$0.29 \pm 0.05$	$0.32 \pm 0.05$	$0.92 \pm 0.27$		$0.31 \pm 0.09$
		$0.33 \pm 0.05$	$0.89 \pm 0.27$		$0.32 \pm 0.10$
121.2	$0.36 \pm 0.05$	$0.28 \pm 0.04$	$0.78 \pm 0.23$		$0.35 \pm 0.12$
	$0.32 \pm 0.05$	$0.30 \pm 0.05$			
131.0	$0.35 \pm 0.05$	$0.30 \pm 0.05$	$0.90 \pm 0.14$	$0.16 \pm 0.07$	$0.38 \pm 0.06$
	$0.32 \pm 0.05$	$0.24 \pm 0.04$			
140.9	$0.37 \pm 0.06$	$0.29 \pm 0.05$	$0.91 \pm 0.14$	$0.15 \pm 0.07$	$0.36 \pm 0.05$
	$0.30 \pm 0.05$	$0.28 \pm 0.04$			$0.315 \pm 0.05$
150.7	$0.30 \pm 0.05$	$0.23 \pm 0.04$	$0.70 \pm 0.11$	$0.16 \pm 0.05$	$0.34 \pm 0.05$
	$0.23 \pm 0.04$	$0.23 \pm 0.04$	$0.68 \pm 0.10$		$0.27 \pm 0.04$
160.5	$0.21 \pm 0.03$	$0.21 \pm 0.03$	$0.52 \pm 0.08$	$0.11 \pm 0.04$	$0.25 \pm 0.05$
	$0.19 \pm 0.03$	$0.20 \pm 0.03$			

TABLE 3

Tentative spin assignment and corresponding calculated and experimental cross sections of four levels of  $Sc^{45}$ .

$$\gamma = 40^\circ ; \theta = 40.9^\circ$$

	$Ti^{46}$	$Sc^{45}$			
$Q$	- 0.885	- 0.376	- 0.719	- 1.236	- 1.661
$U(\theta)$	MeV	MeV	MeV	MeV	MeV
(mb/sr)	$2^+$	$5/2^-$	$3/2^-$	$11/2^-$	$9/2^-$
$\sigma_{exp}(\theta)$	8.02	$0.89 \pm 0.40$	$0.83 \pm 0.33$	$2.17 \pm 0.43$	$0.99 \pm 0.15$
$\sigma_{calc}(\theta)$		$1.20 \pm 0.06$	$0.80 \pm 0.04$	$2.41 \pm 0.12$	$2.00 \pm 0.10$

$$\gamma = 60^\circ ; \theta = 61.2^\circ$$

$\sigma_{exp}(\theta)$	4.19	$0.50 \pm 0.17$	$0.45 \pm 0.16$	$1.20 \pm 0.24$	$0.51 \pm 0.08$
$\sigma_{calc}(\theta)$		$0.63 \pm 0.03$	$0.42 \pm 0.02$	$1.26 \pm 0.06$	$1.05 \pm 0.05$

$$\gamma = 70^\circ ; \theta = 71.3^\circ$$

$\sigma_{exp}(\theta)$	3.73	$0.41 \pm 0.12$	$0.33 \pm 0.11$	$1.05 \pm 0.21$	$0.36 \pm 0.09$
$\sigma_{calc}(\theta)$		$0.56 \pm 0.03$	$0.37 \pm 0.02$	$1.12 \pm 0.05$	$0.93 \pm 0.04$

$$\gamma = 120^\circ ; \theta = 121.2^\circ$$

$\sigma_{exp}(\theta)$	2.74	$0.36 \pm 0.05$	$0.28 \pm 0.04$	$0.78 \pm 0.23$	$0.35 \pm 0.12$
$\sigma_{calc}(\theta)$		$0.41 \pm 0.01$	$0.27 \pm 0.01$	$0.82 \pm 0.03$	$0.68 \pm 0.02$

$$\gamma = 130^\circ ; \theta = 131.0^\circ$$

$\sigma_{exp}(\theta)$	2.91	$0.35 \pm 0.05$	$0.30 \pm 0.05$	$0.90 \pm 0.13$	$0.38 \pm 0.06$
$\sigma_{calc}(\theta)$		$0.44 \pm 0.02$	$0.29 \pm 0.01$	$0.87 \pm 0.03$	$0.73 \pm 0.03$

$$\gamma = 140^\circ ; \theta = 140.9^\circ$$

$\sigma_{exp}(\theta)$	3.03	$0.37 \pm 0.06$	$0.29 \pm 0.04$	$0.91 \pm 0.14$	$0.36 \pm 0.05$
$\sigma_{calc}(\theta)$		$0.45 \pm 0.02$	$0.30 \pm 0.01$	$0.91 \pm 0.04$	$0.76 \pm 0.03$

$$\gamma = 150^\circ ; \theta = 150.7^\circ$$

$\sigma_{exp}(\theta)$	2.64	$0.30 \pm 0.05$	$0.23 \pm 0.03$	$0.70 \pm 0.11$	$0.34 \pm 0.05$
$\sigma_{calc}(\theta)$		$0.40 \pm 0.02$	$0.26 \pm 0.01$	$0.79 \pm 0.03$	$0.66 \pm 0.03$

$$\gamma = 160^\circ ; \theta = 160.5^\circ$$

$\sigma_{exp}(\theta)$	1.84	$0.21 \pm 0.03$	$0.21 \pm 0.03$	$0.52 \pm 0.08$	$0.25 \pm 0.05$
$\sigma_{calc}(\theta)$		$0.28 \pm 0.01$	$0.18 \pm 0.01$	$0.55 \pm 0.03$	$0.46 \pm 0.02$

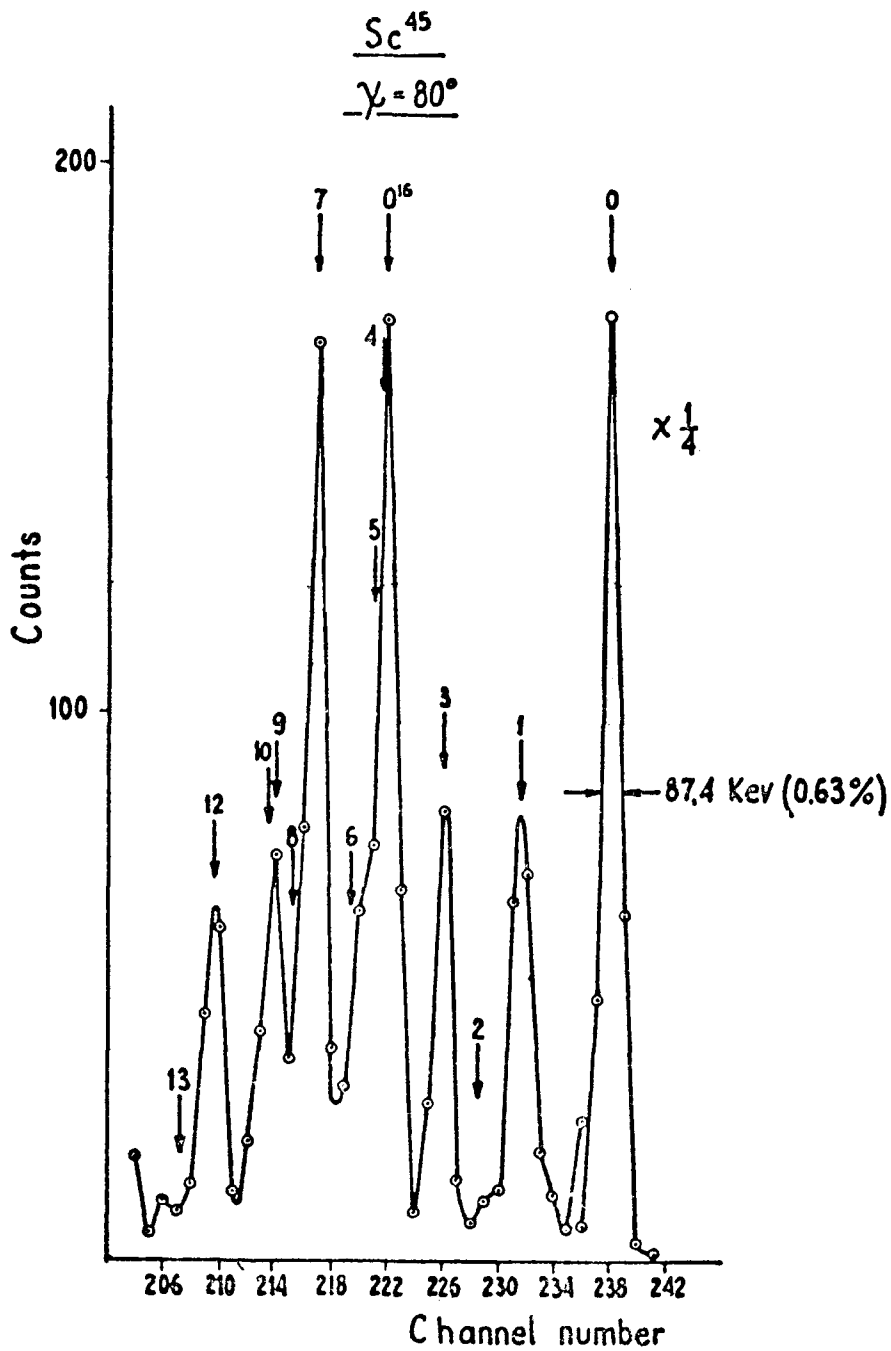


Figure 1. — Spectrum of  $\text{Sc}^{45}$  taken at  $\psi = 80^\circ$  (laboratory angle). The ground state peak (0) shows a resolution of 87.4 keV (0.63%).

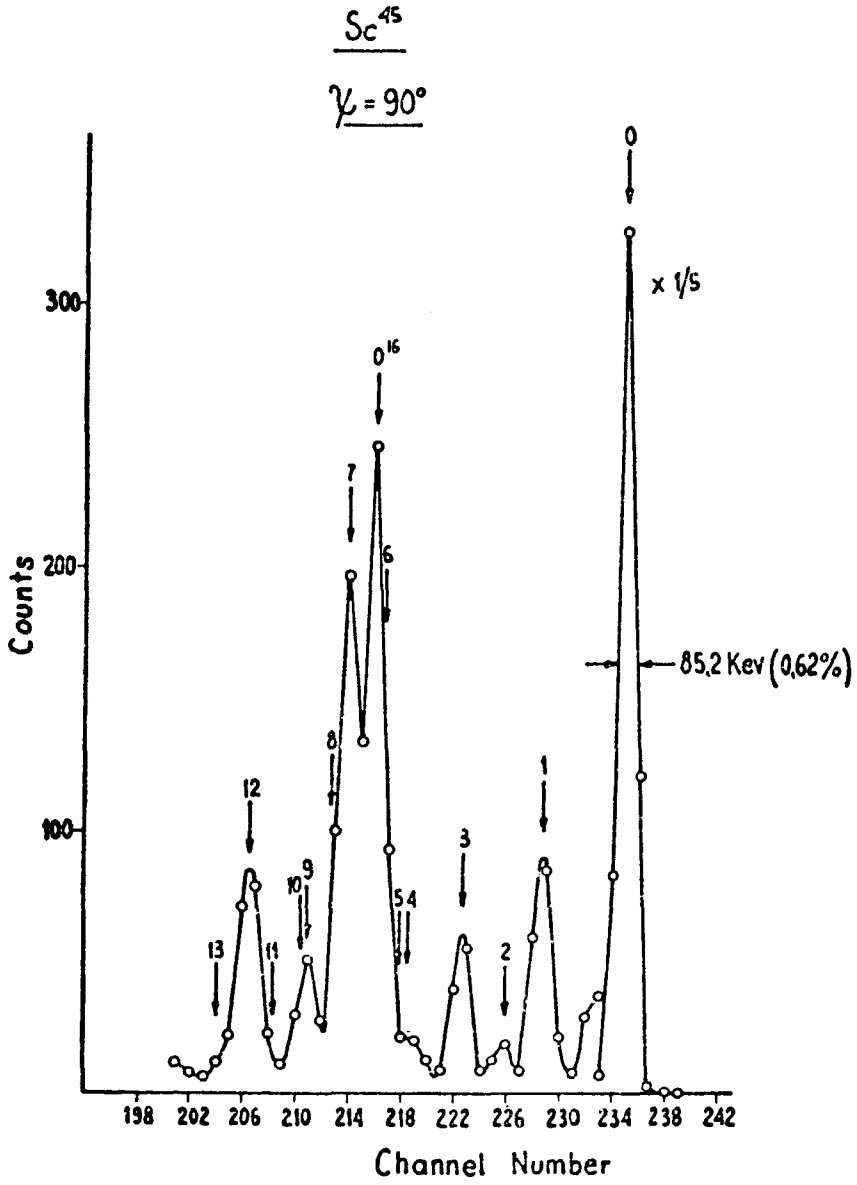


Figure 2. — Spectrum<sub>1</sub> of Sc<sup>45</sup> taken at  $\psi = 90^\circ$ . Resolution is 85.2 keV (0.62 %).

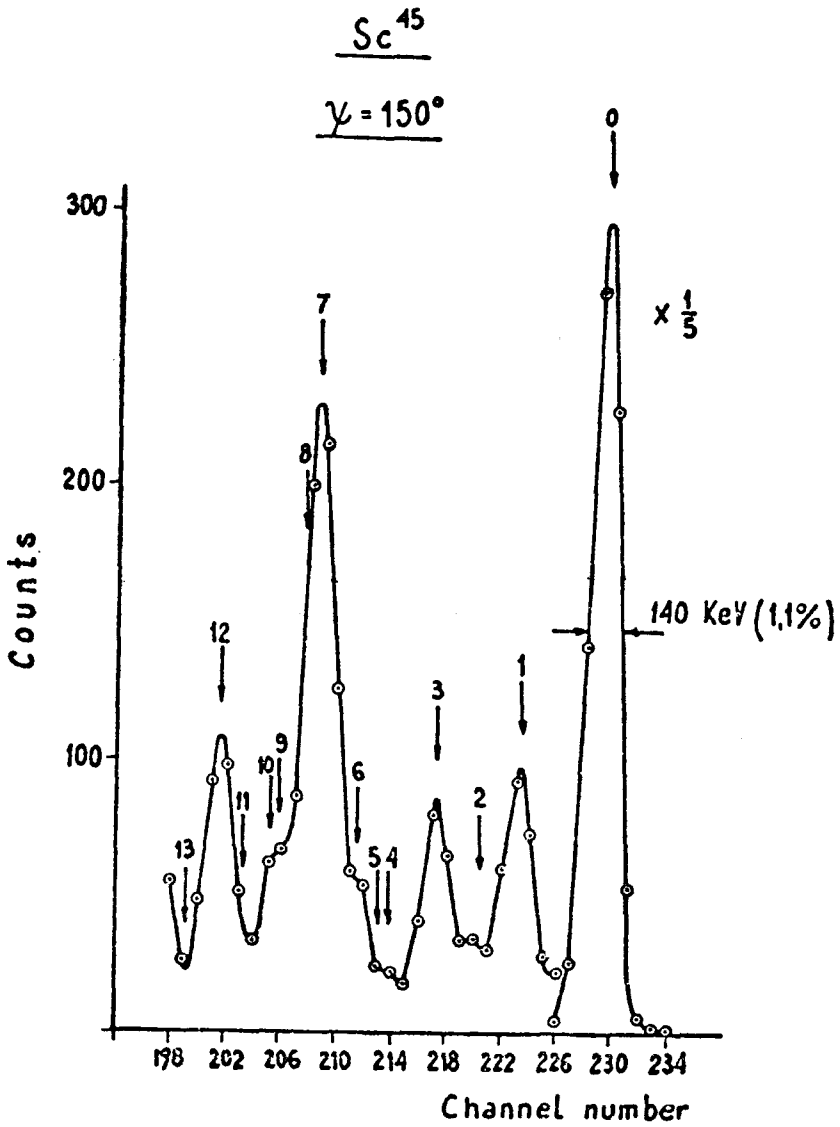


Figure 3. — Spectrum of  $\text{Sc}^{45}$  taken at  $\psi = 150^\circ$ . Resolution now is 140 keV (1.1%). The doublet at 1.408 - 1.432 MeV is not resolved from the 1.236 MeV peak.

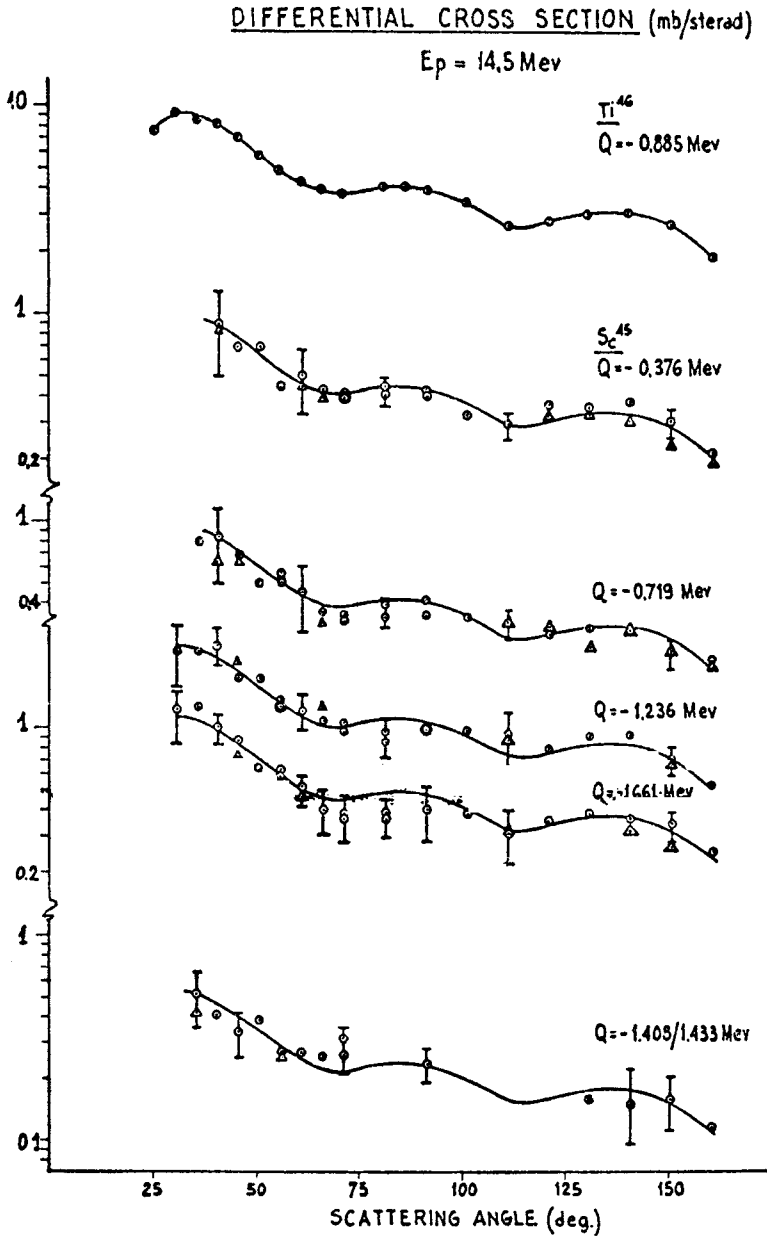


Fig. 4. — Inelastic angular distributions for the first excited level ( $2^+$ ) of  $\text{Ti}^{46}$  and the levels at 0.376, 0.719, 1.236, 1.408 - 1.433 (not resolved) and 1.661 MeV of  $\text{Sc}^{45}$  (Center of mass system)

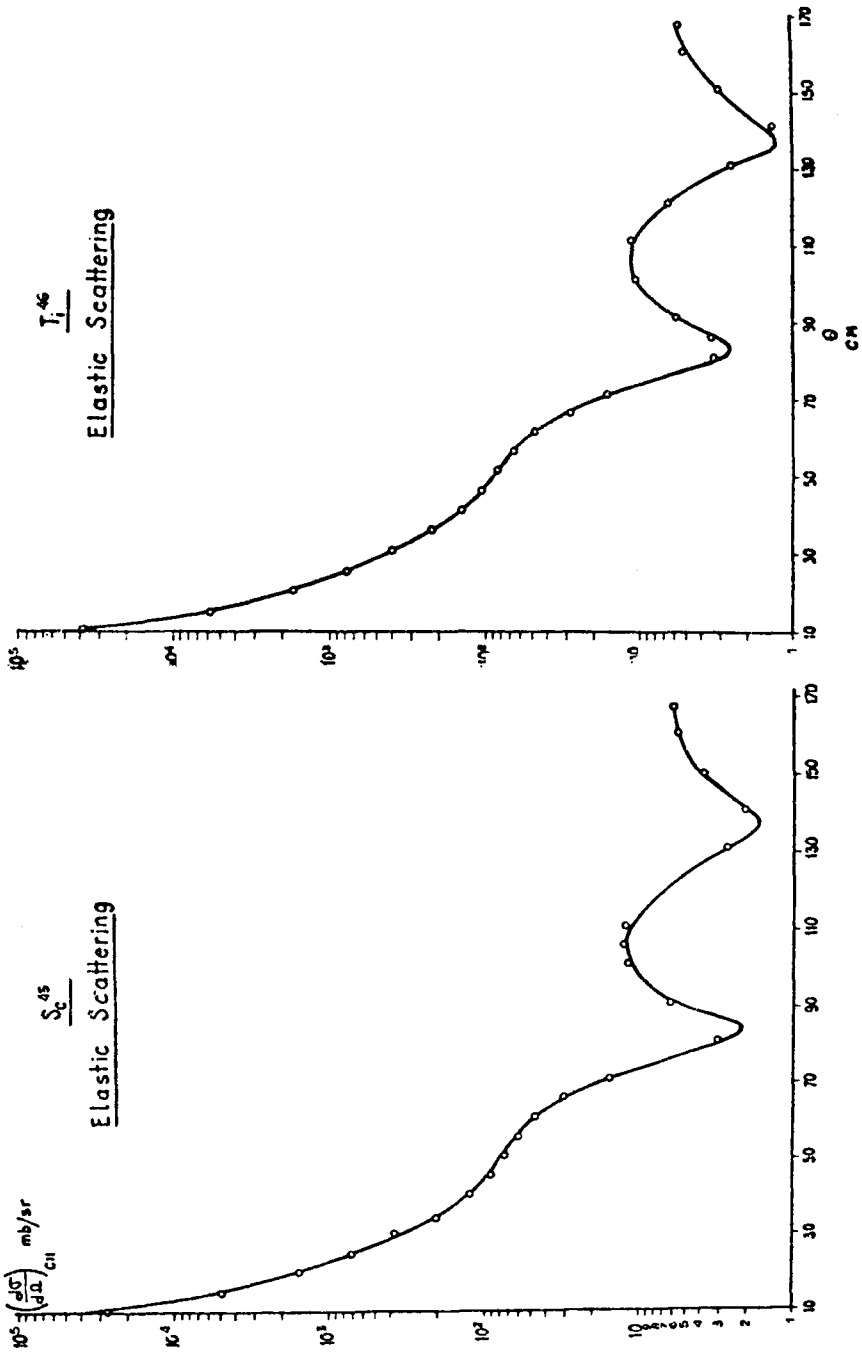


Fig. 5. — Experimental elastic angular distributions for Sc<sup>45</sup> and Ti<sup>40</sup> (Center of mass system).

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