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K. Grotowski, F. Pellegrini and S. Wiktor : LEVEL STRUCTURE OF ^{48}Sc FROM THE $^{50}Ti(d,\alpha)^{48}Sc$ REACTION. -

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SUMMARY.

The ^{50}Ti(d,α)^{48}Sc reaction was investigated using deuterons with the energy of 12.9 MeV. Energy spectra and angular distributions of α-particles emitted in this reaction have been measured. Relatively large cross-sections were found for transistions leading to the 0.14, 1.06 and 2.03 MeV excited states of the residual ^{48}Sc nucleus. The spin and parity values suggested for the 0.14 MeV state and the not observed previously 1.06 MeV state are $J^{\pi} = 5^+$ and $J^{\pi} = 7^+$ respectively.

1 - INTRODUCTION -

The ^{48}Sc is an interesting nucleus for the reason of its one particle - one hole configuration. One proton and seven neutrons form particle-hole states in the $1f_{7/2}$ shell outside the ^{40}Ca core. The low-lying levels of the ^{48}Sc nucleus arising from neutron hole - proton interaction are expected to have spin and parity ranging from $J^{\pi} = 0^+$ to $J^{\pi} = 7^+$.

Experimental information about the level structure of ^{48}Sc nucleus is only that obtained in the ^{48}Ca(p, n γ)^{48}Sc[(1, 2)] and ^{49}Ti(d, ^{3}He)^{48}Sc[(3)] reactions. The shell model predicts a $J^{\pi} = 7^+$ state of the ^{48}Sc nucleus at about 1.3 MeV excitation energy[(8)]. This state was not found in the experiments mentioned above. A large angular momentum transfer is necessary in order to create such a state. Because of its kinematics, the (d,α) reaction should give some information about the high spin levels of ^{48}Sc nucleus.

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2 - EXPERIMENTAL PROCEDURE -

The experiment was performed using a beam of 12,9 MeV deuterons from the 120 cm cyclotron of the Institute of Nuclear Physics in Cracow. A TiO_2 target with the thickness of about 0.8 mg/cm^2 was placed in the centre of the scattering chamber. The target was prepared by sedimentation on a thin carbon backing,of a very fine TiO_2 powder suspended in water. The ^{50}Ti isotope was enriched to 89%. The momentum of α -particles emitted in (d,α) reaction was analyzed using a magnetic spectrograph with nuclear emulsions as detector. The obtained energy resolution was about 330 KeV. Angular distributions of α-particles were measured in 5^o steps for the range of angles from 20 up to 90 degrees lab. The total charge of deuterons collected in the Faraday cup, placed behing the target, was measured by a beam integrator. The intensity of the beam was measured independently by a semiconductor monitor viewing a thin gold target placed in front of a mean target. An additional semiconductor counter monitor looking at the TiO_2 target was applied in order to ckeck its thickness continuously during the measurements. The nuclear emulsions used as detectors in magnetic spectrograph were exposed in vacuum. For each exposure a charge of 3800-5700 μC was collected in the Faraday cup in order to provide a large enough number of α-particle tracks.

The contribution of α-particles corresponding to the (d,) reactions on other Ti isotopes was estimated by additional measurements made for the natural Ti target.

3 - EXPERIMENTAL RESULTS -

A typical α-particle spectrum obtained at an angle of 70 degrees in the lab. system is shown in fig. 1. All the α-particle energy spectra were analyzed by means of a Gaussian method using an electronic computer. The experimental data were fitted by a least square procedure to a function:

$$Y=\sum A_k(\sqrt{2\pi}\sigma)^{-1}\exp\left[-0.5(X_k-X)^2\sigma^{-2}\right] + \text{background}$$

A_k - total number of α-particles corresponding to the k-th energy peak,
X - coordinate on the energy axis,
X_k - mean energy of the k-th energy peak.

Because of the limited energy resolution of the experimental arrangement, our measurements included only four α -particle groups from the $^{50}Ti(d,\alpha)^{48}Sc$ reaction and one intensive group from the $^{16}O(d,\alpha)^{14}N$ reaction.

Fig. 2 shows angular distributions of α-particles corresponding to the 0.14 and 1.06 states of ^{48}Sc. The 0.60 and 2.03 MeV states were visible in the energy spectra only for few angles. The error of the absolute value of the measured cross-sections was estimated to be $\pm 40\%$, while relative errors were of the order of 25%.

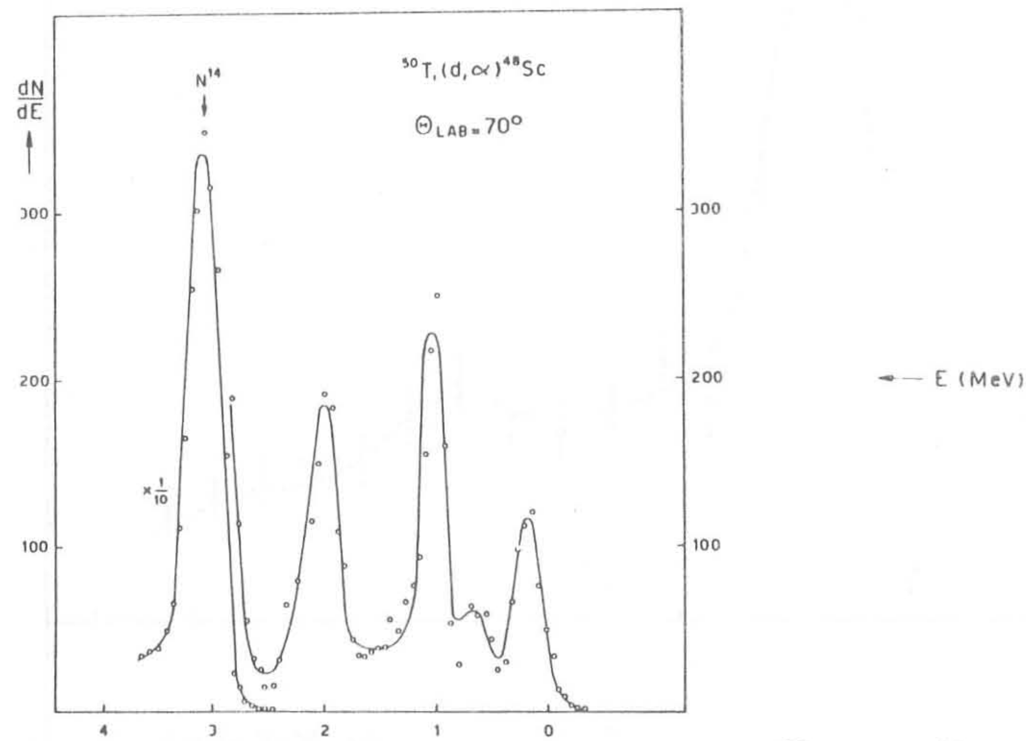

FIG. 1 - Spectrum of α-particles from the ^{50}Ti(d,α)^{48}Sc reaction obtained at 70 degrees in the laboratory system.

Table I shows the energy levels of ^{48}Sc, excited in the ^{50}Ti(d,α)^{48}Sc reaction, together with those identified in the previous (d,^{3}He)(3) and (p, n)(1,2) investigations.

TABLE I

^{50}Ti(d,α)^{48}Sc E_x (MeV)	^{49}Ti(d,^{3}He)^{48}Sc E_x (MeV)	^{48}Ca(p,nγ)^{48}Sc E_x (MeV)
-	0	0
0.14 $\pm$ 0.04		0.131
		0.253
0.60 $\pm$ 0.04	0.77	0.624
1.06 $\pm$ 0.04		
		1.144
	1.40	1.406
2.03 $\pm$ 0.04	2.01	2.192
		2.276
		2.519

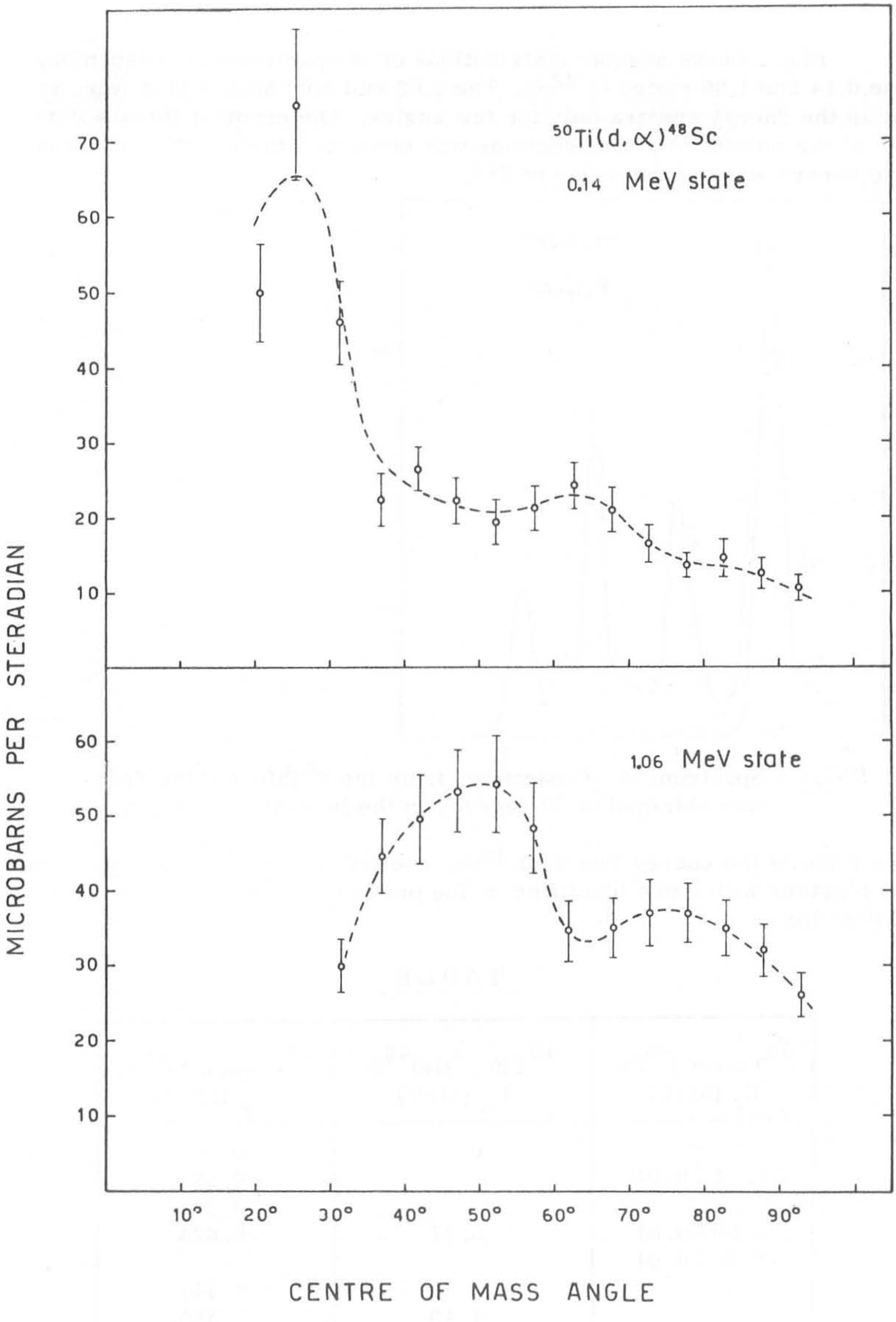

FIG. 2 - Angular distribution of α-particles leading to the 0. 14 MeV and to the 1. 06 MeV states of ^{48}Sc nucleus.

4 - DISCUSSION -

According to the shell model picture of the ^{48}Sc nucleus, its low-lying states should correspond to the different couplings of a neutron hole and proton in the $lf_{7/2}$ shell outside the ^{40}Ca core. The 1.06 MeV state is excited with the highest cross-section. Angular distribution of α-particles corresponding to this state shows a broad maximum in the angular region between 40 and 60 degrees in the centre of mass system. These two experimental facts suggest that the 1.06 MeV state of ^{48}Sc can be identified as the 7^+ state.

A (d,α) reaction can be treated as a quasi deuteron pick-up process(4,5). In such a case the two picked up nucleons are coupled to the highest angular momentum, what classically corresponds to the motion with coplanar orbits. Therefore in the $^{50}Ti(d,\alpha)^{48}Sc$ reaction the intensity of transition is expected to decrease with decreasing spin of the residual nucleus.

For the allowed spin states of the residual ^{48}Sc nucleus: 7^+, 5^+, 3^+ and 1^+ the orbital angular momenta are respectively L=6, (4,6), (2, 4) and (0,2). Table II presents the L-S components of two $lf_{7/2}$ nucleons coupled to the odd J spin values. Excluding the odd L value terms of the 5^+, 3^+ and 1^+ states, we see that the transition to the 7^+ (L=6) state should have the highest probability.

It is easy to show that at our bombarding energy there is enough momentum transfer to excite the 7^+ state. In the semiclassical picture the transferred angular momentum L is given by the relation $L=R\,|(48/50)\hat{k}_d-\hat{k}_\alpha|$. Taking the interaction radius $R=1.5A^{1/3}$fm, we get $6\hbar \leq L \leq 8\hbar$ in angular region of the emitted α-particles from 40 to 60 degrees in the centre of mass system. This is in agreement with the measured angular distributions corresponding to the 1.06 MeV state of ^{48}Sc nucleus.

Additional experimental evidence for the spin value assigned above to the 1.06 MeV state can be supplied by the angular distributions of deuterons from the $^{40}Ca(\alpha, d)^{42}Sc$ reaction studied at the energy of bombarding α-particles 24.7 MeV(6). In the shell model picture one proton and one neutron outside the ^{40}Ca core, in the ^{42}Sc nucleus, correspond to the one neutron hole and one proton in ^{48}Sc nucleus. There is experimental evidence(6,7) that the 0.60 MeV state of ^{42}Sc is a 7^+ state with the configuration $(lf_{7/2})^2$. Because of the similar mechanism of (α, d) and (d,α) reactions we can expect in both cases similar angular distributions plotted against momentum transfer. The comparison is shown in Fig. 3. Of course the different nuclear and coulomb distortions in both reaction channels must destroy some of the resemblance between angular distributions, but nevertheless the agreement is quite good.

The next $J^{\pi}=5^+$ state of the neutron hole-proton multiplet seems to be that at 0.14 MeV, identified in the investigation of $^{48}Ca(p,n\gamma)^{48}Sc$ reaction(1). We see from Table II that the dominant angular momentum transferred for the 5^+ state is L=4 and such a momentum transfer, calculated from the equation $L=R\,|(48/50)\hat{k}_d-\hat{k}_\alpha|$ is expected for the α-particles emitted in the angular region near 20 degrees in the centre of mass system. This is verified by the angular distribution shown in Fig. 2.

TABLE II

The states of $(1f_{7/2})^2_J$ configuration	L-S wave functions
7	$1.00\ {}^3I_7$
5	$-\sqrt{\frac{6}{539}}\,{}^3I_5+\sqrt{\frac{390}{539}}\,{}^3G_5+\sqrt{\frac{143}{539}}\,{}^1H_5$
3	$-\sqrt{\frac{24}{343}}\,{}^3G_3+\sqrt{\frac{165}{343}}\,{}^3D_3+\sqrt{\frac{154}{343}}\,{}^1F_3$
1	$-\sqrt{\frac{10}{49}}\,{}^3D_1+\sqrt{\frac{12}{49}}\,{}^3S_1+\sqrt{\frac{27}{49}}\,{}^1P_1$

The ground state of ^{48}Sc nucleus with the spin and parity 6^+ was not excited in the present experiment, what can be due to the special selection rule for (d,α) reaction forbidding transitions in which the even angular momentum is transferred.

Comparing our results with those obtained in the ^{48}Ca$(p,n\gamma)^{48}$Sc reaction, we see that in the vicinity of 1.06 MeV level, found in our experiment, exists a 1.144 MeV level observed by the authors of reference(1). We can argue that this 1.144 MeV level is not the $J^\pi=7^+$ one. If this reaction proceeds by a direct knockout mechanism, the $J^\pi=7^+$ level can be excited only for the momentum transfer at least of 6h. The highest momentum transfer possible in this reaction for the 3.25 MeV energy of incoming protons used in that experiment(1) is 3h. On the other hand, if this reaction proceeds by a compound nucleus mechanism, the excitation of the 7^+ level seems to be very improbable because of the low penetrability of the potential barrier and the not high enough value of transferred momentum. The target nucleus has a $J^\pi=0^+$ spin value. The spin of the compound ^{49}Sc nucleus is equal $\ell_p\pm1/2$, where ℓ_p is the orbital angular momentum of the incoming proton. At this low bombarding proton energy the highest partial waves are the "d" waves and the largest spin of the compound nucleus is 5/2. Such a state should decay by the emission of "g" wave neutron in order to form a 7^+ state of the residual ^{48}Sc nucleus. For "g" neutrons with the energy of about 1.5 MeV the probability of escaping through a centrifugal barrier, which is of the order of 15 MeV, is negligible.

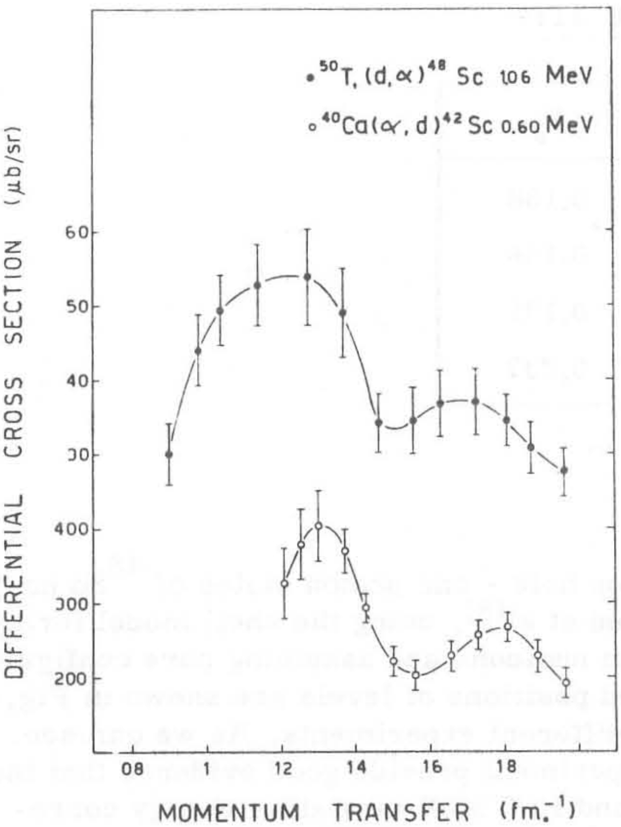

FIG. 3 - Differential cross-sections plotted against momentum transfer in the reaction $^{50}Ti(d,\alpha)^{48}Sc$ (upper curve) and in the reaction $^{40}Ca(\alpha,d)^{42}Sc$ (lower curve).

For the same reasons as mentioned above, the 5^+ level of ^{48}Sc at 0.14 MeV, appreciably populated in our experiment, was excited with a very small cross-section in the reaction $^{48}Ca(p,n\gamma)^{48}Sc$(1).

It is rather strange that the 7^+ state of ^{48}Sc nucleus was not observed in $^{49}Ti(d,^3He)^{48}Sc$ reaction ad a bombarding energy of 21 MeV(3). In order to estimate the probability of excitation of this state in the $^{49}Ti(d,^3He)^{48}Sc$ reaction, we calculated spectroscopic factors for the transitions to final states of ^{48}Sc in which one proton is removed from the $1f_{7/2}$ shell. Taking for the ^{48}Sc nucleus the following wave function:

$$\psi(^{48}Sc)_J = \left[\psi(f_{7/2})_p \, \psi(f_{7/2})_n^{-1} \right]_J$$

and for the ^{49}Ti target nucleus the wave function given by the authors of ref. (8):

$$\begin{aligned}\psi(^{49}Ti)_{7/2} = & -0.9136 \left[\psi(f_{7/2},0)_p^2 \, \psi(f_{7/2})_n^{-1} \right]_{7/2} + \\ & +0.4058 \left[\psi(f_{7/2},2)_p^2 \, \psi(f_{7/2})_n^{-1} \right]_{7/2} + \\ & +0.0916 \left[\psi(f_{7/2},4)_p^2 \, \psi(f_{7/2})_n^{-1} \right]_{7/2} + \\ & -0.0146 \left[\psi(f_{7/2},6)_p^2 \, \psi(f_{7/2})_n^{-1} \right]_{7/2} ,\end{aligned}$$

we get spectroscopic factors S_J shown in Table III.

As we can see from this Table, the 7^+ state should be highly populated. The only possible explanation for this discrepancy can be found in a rather bad energy resolution and a high level of background in the energy spectrum presented by the authors of reference(3).

TABLE III

J	S_J
6^+	0.188
5^+	0.156
4^+	0.131
7^+	0.237

5 - CONCLUSION -

Parameters of the one neutron hole - one proton states of ^{48}Sc nucleus have been calculated by McCullen et al[8], using the shell model formalism with effective interaction between nucleons and assuming pure configurations in the $lf_{7/2}$ shell. The calculated positions of levels are shown in Fig. 4 together with level schemes found in different experiments. As we can see, the results obtained in the present experiment provide good evidence that the levels of ^{48}Sc nucleus found at 0.14 and 10.6 MeV excitation energy correspond to the 5^+ and 7^+ states in qualitative agreement with the predictions of the shell model theory.

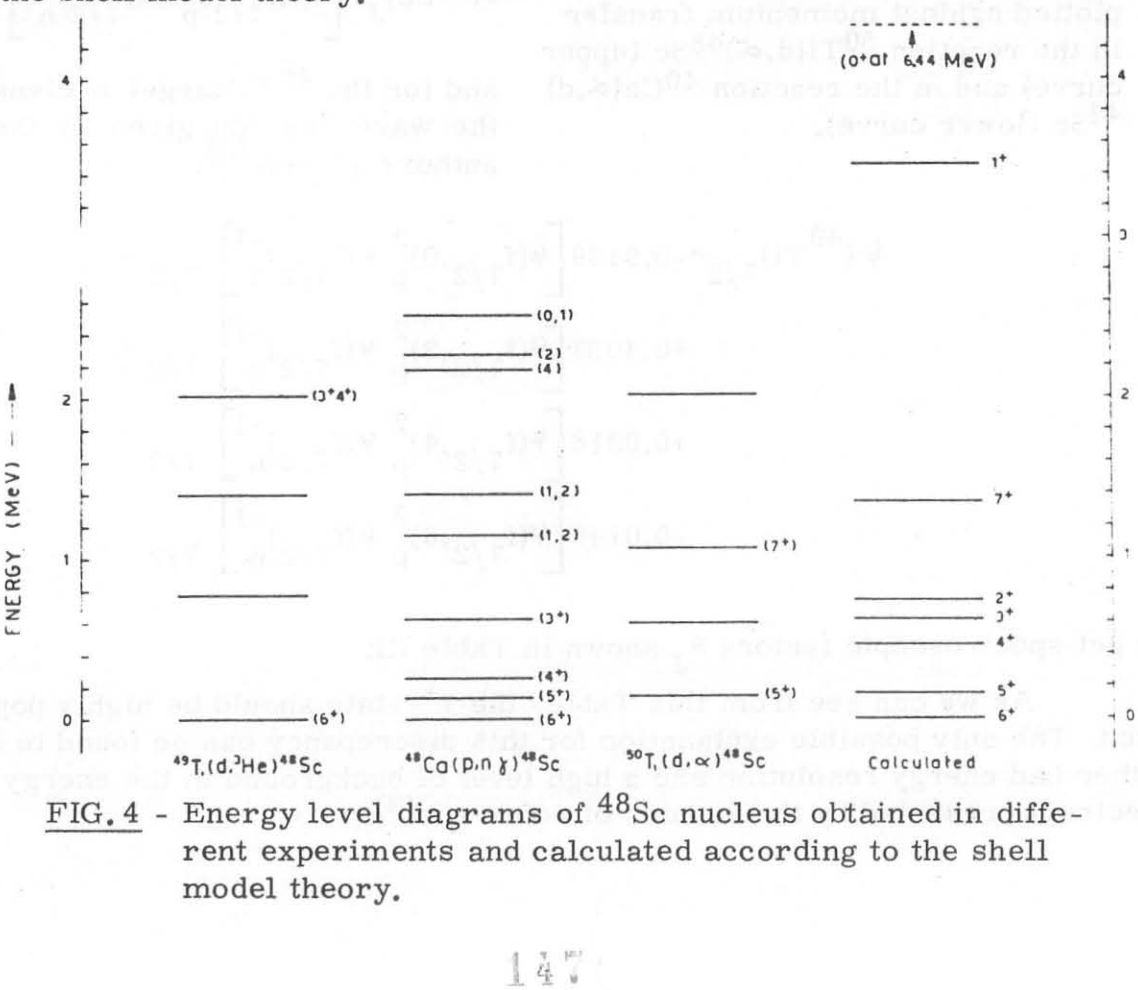

FIG. 4 - Energy level diagrams of ^{48}Sc nucleus obtained in different experiments and calculated according to the shell model theory.

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