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LOWER EXCITED STATES OF $^{50}_{22}Ti_{28}$

by

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Lower Excited States of ${}^{50}_{22}\mathrm{Ti}_{28}$ (*).

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(ricevuto l'8 Giugno 1962)

Summary. — A detailed investigation of the decay of ^{50}Sc (1.7 min) has been undertaken by scintillation techniques. ^{50}Sc has been produced by (n, p) reactions with 14 MeV neutrons on metallic titanium foils. The level structure of the two-$f_{\frac{7}{2}}$ proton configuration in ^{50}Ti has been well established with the following sequence: 0 (0^+); 1570 keV (2^+); 2695 (4^+); 3215 (6^+). A complete decay scheme of ^{50}Sc is proposed, with β-transitions to the 6^+ and 4^+ states in ^{50}Ti. On this basis it is assumed that the spin of the ^{50}Sc ground state is 5^+ as expected by the shell model; however the β-transition probabilities can be explained assuming a configuration mixing between $(f_{\frac{7}{2}})(p_{\frac{3}{2}})$ and $(f_{\frac{7}{2}})(f_{\frac{5}{2}})$ couplings.

1. – Introduction.

Two identical particles with total angular momentum j in a doubly magic core gives a sequence of levels 0, 2, 4 ... $(2j-1)$. A detailed knowledge of such sequence is important to understand the forces to be used in shell model calculations (1).

There are, however, only a few cases where this sequence is well known. One specifically interesting case is that of two $1f_{\frac{7}{2}}$ nucleons since this is a single j shell and both $(\nu f_{\frac{7}{2}})^2$ (neutrons) and $(\pi f_{\frac{7}{2}})^2$ (protons) configurations are acces-

(*) Work performed under a contract between EURATOM and C.N.E.N.
(**) Permanent address: Department of Physics, University of Tokyo.
(1) C. LEVINSON and K. W. FORD: *Phys. Rev.*, **100**, 13 (1955); R. D. LAWSON and J. L. URETKSKY: *Phys. Rev.*, **106**, 1369 (1957); I. TALMI: *Proc. Rehovoth Conf. Nucl. Struct. 1957*, (1958), pp. 31-45; *Phys. Rev.*, **126**, 1096 (1962); I. TALMI and I. UNNA: *Ann. Rev. Nucl. Sci.*, **10**, 353 (1960).

sible experimentally. The cases in point are $^{42}_{20}Ca_{22}$ and $^{50}_{22}Ti_{28}$ respectively, both with doubly magic, although different, core.

Recently a high-spin isomer of ^{42}Sc was found to decay to a high-spin state of ^{42}Ca which apparently cascades through the above mentioned sequence (2).

The situation seems to be quite similar to that of ^{50}Ti (3); however some doubt in the level assignement of ^{50}Ti (4) did not permit a conclusive comparison.

In order to know the level sequence of ^{50}Ti more precisely, we tried to investigate the decay of ^{50}Sc very carefully.

2. – Measurements and results.

Titanium metallic foils (99.9% purity) were bombarded with 14 MeV neutrons of the AN 400 accelerator for ~ 2 min, and the activity was measured no more than 30 s after the end of the irradiation. The γ-ray activity was measured with the conventional γ scintillation spectrometer of our laboratory (75 mm $\times$ 75 mm well type NaI(Tl) crystal coupled to a 6363 DuMont photomultiplier and connected to a 200 channel LABEN analyser).

The β-ray activity was measured with a scintillation spectrometer consisting of an antracene crystal (36 mm diameter, 25 mm height) calibrated with the end point energies of the β^- spectra of ^{19}O (4.6 MeV) and ^{28}Al (2.87 MeV), in the same condition of geometry and backing.

The half life was followed, in every case, for at least 30 min; the result found: (1.7 ± 0.1) min, is in good agreement with that previously reported (4). The long-lived activities produced, *i.e.* ^{45}Ti ($T_{\frac{1}{2}} = 3.1$ hours) and ^{48}Sc ($T_{\frac{1}{2}} = 1.8$ days) were well recognized and the relative contribution taken into account. For the β-ray spectrum this contribution was expected, and indeed found, to be unimportant for energies larger than 1 MeV.

Figure 1 displays the γ scintillation spectrum taken shortly after the irradiation and the corresponding one taken 30 min later. Three γ-rays with energies 520, 1125 and 1570 keV were clearly identified in the short-lived activity, whereas the pulse height distribution due to the long-lived part check very well with that expected for ^{45}Ti and ^{48}Sc.

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(2) J. W. Nelson, H. S. Plendl and J. D. Oberholtzer: *Proc. of the Rutherford Jubilee Int. Conf. Manchester 1961; Bull. Am. Phys. Soc.*, **7**, 286 (1962); P. C. Rogers and G. E. Gordon: M.I.T. Lab. Nucl. Sci. Progress Report, May 1, 12 (1962).

(3) H. Morinaga, N. Mutsuro and M. Sugawara: *Phys. Rev.*, **114**, 1146 (1959).

(4) H. Morinaga and F. Bleuler: *Phys. Rev.*, **100**, 1236 (1955); H. Morinaga: U.S. AEC Report COO-173 (1956), p. 37.

An accurate determination of the energy of the 520 keV γ-ray, which could have been confused with annihilation radiations, was undertaken in the following way: the low energy spectrum of ^{50}Sc was detected in the presence of the 278 keV and 662 keV γ-radiations of ^{203}Hg and ^{137}Cs sources; the same measurement was performed with a ^{22}Na source in the place of ^{50}Sc. The different position of the ^{50}Sc γ-ray and of the 511 keV annihilation peak of ^{22}Na was checked against the ^{203}Hg and ^{137}Cs γ-radiation.

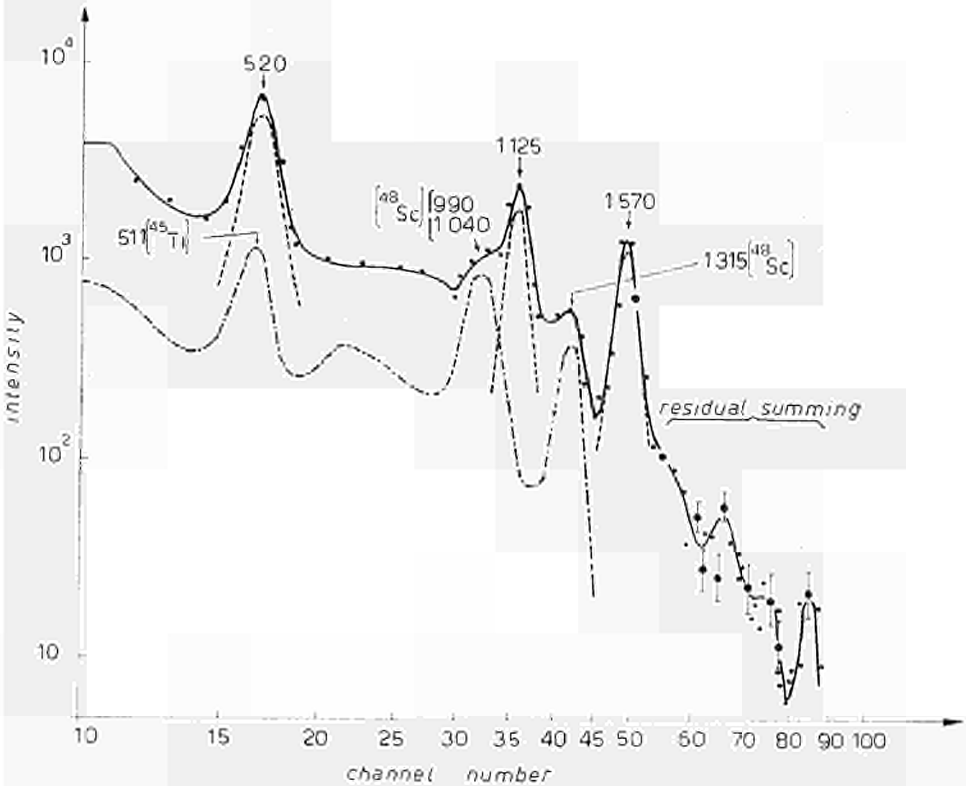


Fig. 1.

This can also be seen in Fig. 1 where the position of the 520 keV γ-ray of ^{50}Sc can be compared with that of the annihilation peak of the long-lived ^{45}Ti after the first one has disappeared. We were able, in this way, to give an energy value of (520 ± 3) keV. The coincidence relationships were determined by the scintillation technique, which, in this case, was of special usefulness.

This is shown in Fig. 2 where the summing spectrum taken with the source in the well of the NaI(Tl) crystal is reported; the contribution of the long-lived activities is also shown in the lower part of the figure. The presence of summing peaks at 3230, 2700, 2100 and 1640 keV is clearly evident and has been interpreted as due to the triple cascade 520-1125-1570 keV.

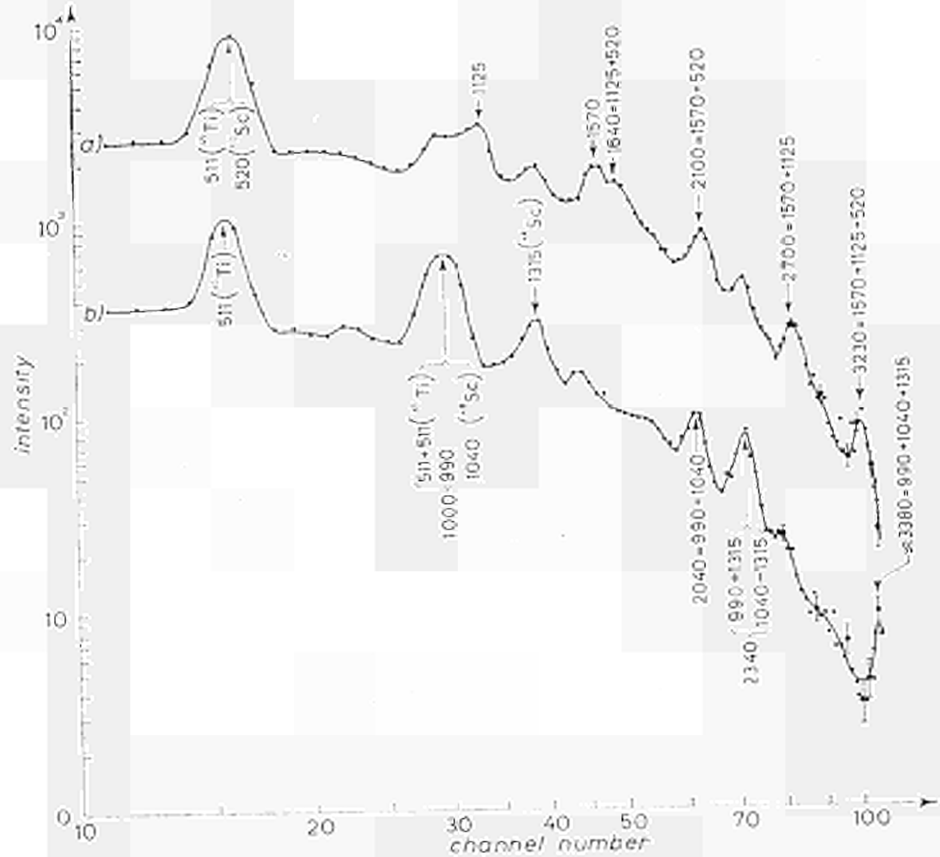
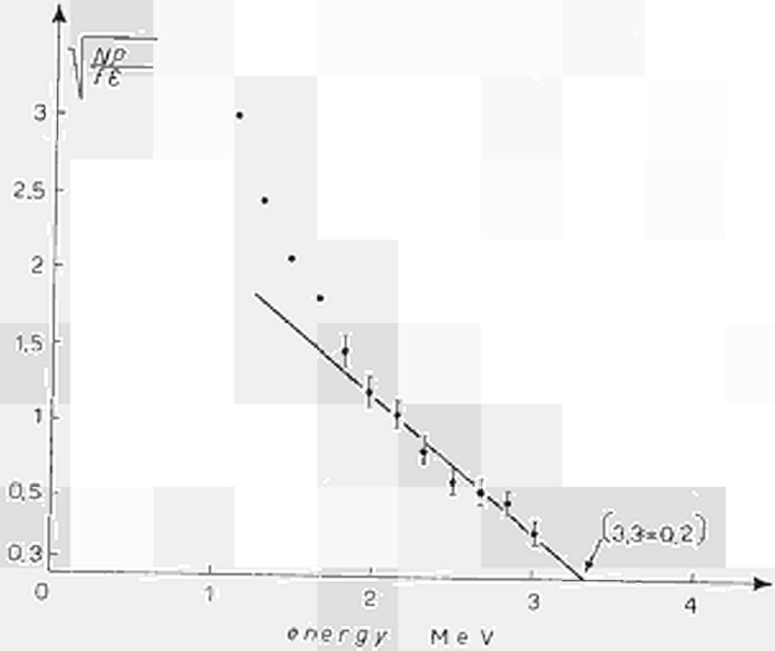


Fig. 2.

The results on γ-rays and γ-γ coincidences are summarized in Table I, where the relative intensities found by analysing the scintillation spectrum in

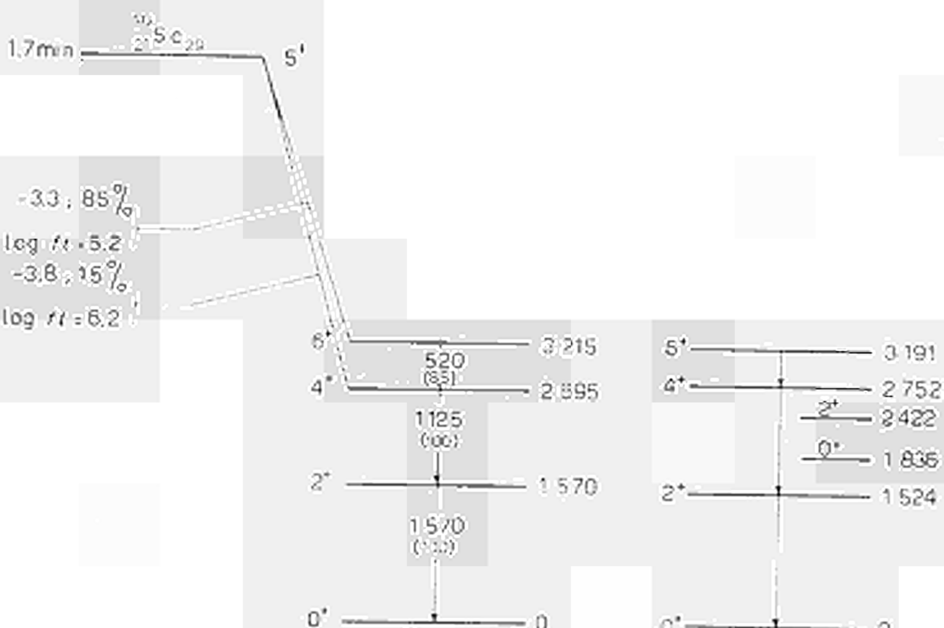
TABLE I.

γ-rays from the decay of ^{50}Sc ($T_{\frac{1}{2}} = (1.7 \pm 0.1)$ min)		Summing peaks from ^{50}Sc	
Energy (keV)	Intensity (%)	Energy (keV)	Interpretation
520 ± 3	85 ± 7	1640 ± 15	$520 + 1125$
1125 ± 10	100 ± 8	2100 ± 10	$520 + 1570$
1570 ± 10	100	2700 ± 10	$1125 + 1570$
—	—	3230 ± 20	$520 + 1125 + 1570$



$\sqrt{\frac{N\rho}{F\varepsilon}}$
3
2,5
2
1,5
1
0,5
0,3
0
1
2
3
4
(3,3±0,2)
energy MeV

Fig. 3.



1,7min
5⁺
-3,3 ; 85%
log ft = 5,2
-3,8 ; 15%
log ft = 6,2
6⁺
3 215
520
(85)
4⁺
2 695
1125
(100)
2⁺
1 570
1 570
0⁺
0
5⁺
3 191
4⁺
2 752
2⁺
2 422
0⁺
1 836
2⁺
1 524
0⁺
0

Fig. 4.

the usual way (5), are reported. They are consistent with an upper level at 3215 keV which decays to the ground state via the triple cascade 520-1125-1570 keV γ-ray producing intermediate levels at 2695 and 1570 keV. The Fermi-Kurie plot of the β-ray spectrum is reported in Fig. 3. An end point energy of (3.4 ± 0.2) MeV was found, which was interpreted as mostly due to the lower energy branch *i.e.* the β transition to the 3215 keV level. Taking into account the relative population of the 2695 keV level as given by the γ-ray intensity balance (85 %), our results are consistent with the assumption of two β branches of energies (3.3 ± 0.1) MeV (85 %) and (3.8 ± 0.2) MeV (15 %) respectively. The decay scheme which can be proposed is shown in Fig. 4, where the level structure of ^{50}Ti is compared with the situation reported for ^{42}Ca.

3. – Discussion.

The level sequence of ^{50}Ti supports very well the expected situation on the basis of the $(\pi f_{\frac{7}{2}})^2$ coupling scheme. The correspondence with the level sequence of ^{42}Ca ($(\nu f_{\frac{7}{2}})^2$ configuration) is really impressive. The 1836 keV (0^+) and the 2422 keV (2^+) levels in ^{42}Ca may be understood as due to core excitations (3).

The similarities of the two-particle spectra in both cases show the validity of the j-j description; it is in fact expected on the basis of such a coupling scheme (1) that the levels with seniority $S=2$ (namely the 2^+, 4^+ and 6^+ levels) would occur at the same energies and that the distance between two successive levels of the $(j)^2$ configuration decreases with increasing spin.

This is also supported for instance by the level sequence in $^{92}_{42}Mo_{50}$, where the $(\pi g_{\frac{9}{2}})^2$ coupling scheme seems to apply (6).

Another interesting remark can be made in connection with the decay of ^{50}Sc.

The relative population of the 6^+ and 4^+ levels in ^{50}Ti suggests a spin 5^+ for the ^{50}Sc ground-state; this is also expected by shell model considerations for a $(f_{\frac{7}{2}})(p_{\frac{3}{2}})$ configuration. This configuration would correspond to a slowing down of the β-decay, because a $p_{\frac{3}{2}} \to f_{\frac{7}{2}}$ transition is l-forbidden, assuming that both 4^+ and 6^+ states in ^{50}Ti come from $(f_{\frac{7}{2}})^2$ pure configuration. This fact is in good agreement with the high experimental $\log ft$ values for the β-decay (5.2 and 6.2 respectively).

Among the possible admixtures to the 5^+ ground state of ^{50}Sc the nearest one which can give rise to β-decay to the $(f_{\frac{7}{2}})^2$ configuration is $(f_{\frac{7}{2}})(f_{\frac{5}{2}})$. If we assume that this admixture is responsible for the β-decay we may try to

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(5) See for instance R. A. Ricci, G. Chilosi, G. Varcaccio, G. B. Vingiani and R. Van Lieshout: *Nuovo Cimento*, **17**, 523 (1960).

(6) R. Van Lieshout, S. Monaro, G. B. Vingiani and H. Morinaga: *Bull. Am. Phys. Soc.*, **7**, 342 (1962).

5

calculate the ratio of the $\log ft$ values of the transition to the 6^+ and 4^+ states as follows.

We assume that the states be describable according to the shell model, with no residual interaction. If the initial state is $[(\pi l_j)(\nu l_{j-1})]_{I_i}$ the Gamow-Teller amplitudes for the decay $[(\pi l_j)(\nu l_{j-1})]_{I_i} \to [(\pi l_j)^2]_{I_f}$ are:

$$M_\mu^{GT} = (-1)^{I_f+1}\left[\frac{(2j-1)(2j+1)(2I_i+1)}{j}\right]^{\frac{1}{2}} \langle 1\, I_i \mu\, M_i | I_f M_f\rangle\, W(j\, j-1\, I_f I_i;\, 1\, j)$$

where I_i, I_f are the total angular momentum of the initial and final states with components M_i and M_f; W the Racah coefficient.

The transition probability is then proportional to

$$|M^{GT}|^2 = \sum_{-1}^{1} M_\mu^{GT*} M_\mu^{GT} = \frac{(2j-1)(2j+1)(2I_i+1)}{j} W^2(j\, j-1\, I_f I_i;\, 1\, j)\,.$$

In particular for ^{50}Sc we assume that the initial state is $[(\pi f_{\frac{7}{2}})(\nu f_{\frac{5}{2}})]_{I_i=5}$ and we use the above formulae with $j=\frac{7}{2}$, $I_i=5$ and $I_f=4$ and 6 for ^{50}Ti.

We find in this way for the ratio of the transition probabilities at the states $I_f=4$ and $I_f=6$ the following result:

$$(ft)_{5\to4}/(ft)_{5\to6} = \frac{5.7}{2}$$

which yields:

$$\log (ft)_{5\to4} - \log (ft)_{5\to6} = 1.24\,.$$

This is in good agreement with the experimental observation.

* * *

We would like to express our thanks to Professor G. Cortini for his interest in this work, to Prof. A. H. Wapstra and M. Jean for interesting stimulating discussions.

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RIASSUNTO

Si è studiata la sequenza di livelli del ^{50}Ti (configurazione protonica $(f_{\frac{7}{2}})^2$) tramite il decadimento del ^{50}Sc (1.7 min) prodotto per reazione (n, p) su titanio metallico. Gli spettri β e γ sono stati determinati con tecniche a scintillazione: tre raggi γ in cascata sono stati chiaramente messi in evidenza con energia (520±3), (1125±10) e (1570±10) KeV corrispondenti alla sequenza di livelli: 0 (0^+), 1570 (2^+), 2695 (4^+) e 3215 (6^+) nel ^{50}Ti. Lo spettro β è consistente con l'esistenza di 2 rami di energia 3.3 e 3.8 MeV che popolano i livelli 6^+ e 4^+ del ^{50}Ti. Si assegna uno spin 5^+ allo stato fondamentale del ^{50}Sc, che probabilmente corrisponde ad una miscela di configurazioni $(f_{\frac{7}{2}})(p_{\frac{3}{2}})$ e $(f_{\frac{7}{2}})(f_{\frac{5}{2}})$. Lo schema di livelli del ^{50}Ti è confrontato con quello del ^{42}Ca.

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