ISTITUTO NAZIONALE FISICA NUCLEARE

INFN/BE - 71/4
24 Maggio 1971

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CROSS-SECTIONS FOR THE PRODUCTION OF GAMMA RAYS FROM THE INTERACTION OF 14.2 MeV NEUTRONS WITH ^{23}Na, ^{32}S, ^{48}Ti AND ^{52}Cr.

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SOTTOSEZIONE DI TRIESTE DELL'INFN

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ABSTRACT

Gamma rays resulting from the interaction of 14.2 MeV neutrons with ^{23}Na, ^{32}S, ^{48}Ti and ^{52}Cr have been investigated.

The differential gamma-ray production cross-sections are presented for gamma rays with energies of 0.44, 0.64, 1.27, 1.63 MeV for ^{23}Na; for gamma rays with energies of 1.27, 2.06, 2.24 MeV for ^{32}S; for gamma rays with energies of 0.99 and 1.31 MeV for ^{48}Ti; for gamma rays with energies of 0.93, 1.33, 1.43 MeV for ^{52}Cr.

The integrated gamma-ray production cross-sections are also given.

1. - INTRODUCTION

The work presented in this report has been performed along the line of a program of measurements of angular distributions of gamma rays produced in the interaction of 14.2 MeV neutrons with various elements.

This report follows the reports INFN/BE-69/8 and INFN/BE-70/6 which treat the same subject and where the results obtained with the nuclei ^{24}Mg, ^{28}Si, ^{56}Fe are shown and the experimental procedure is described.

The last experimental results concerning the nuclei ^{23}Na, ^{32}S, ^{48}Ti and ^{52}Cr, obtained using a 3"x3" NaI (Tl) detector, are reported herein.

2. - EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

The experimental system used to obtain the data reported here has been described in detail elsewhere (1).

All the samples used for the measurements were of the natural isotopic mixture and were right cylinders 6cm in diameter and 12cm long.

Typical gamma-ray spectra taken at 60° for all the samples are shown in figs. 1 to 4. The overall energy resolution characterizing these spectra is of the order of 8.5%.

The analysis of the spectra has been performed by means of a computing program, which is described in detail elsewhere (2), consisting essentially of two parts. One part, which is based on a modified method of Mariscotti (3), determines the energy position of the gamma rays. The other part makes the fit of the gamma peaks, using a function which is a combination of a gaussian with exponential tails, and calculates the areas of the peaks.

In the case of the gamma-ray spectra obtained in the measurements reported here, the areas of the peaks have been determined with an error which is not greater than the error due to the counting statistics and which is anyway as large as 20% in the worst case of unresolved peaks like that of the 2.06 MeV gamma ray of ^{32}S (fig. 2).

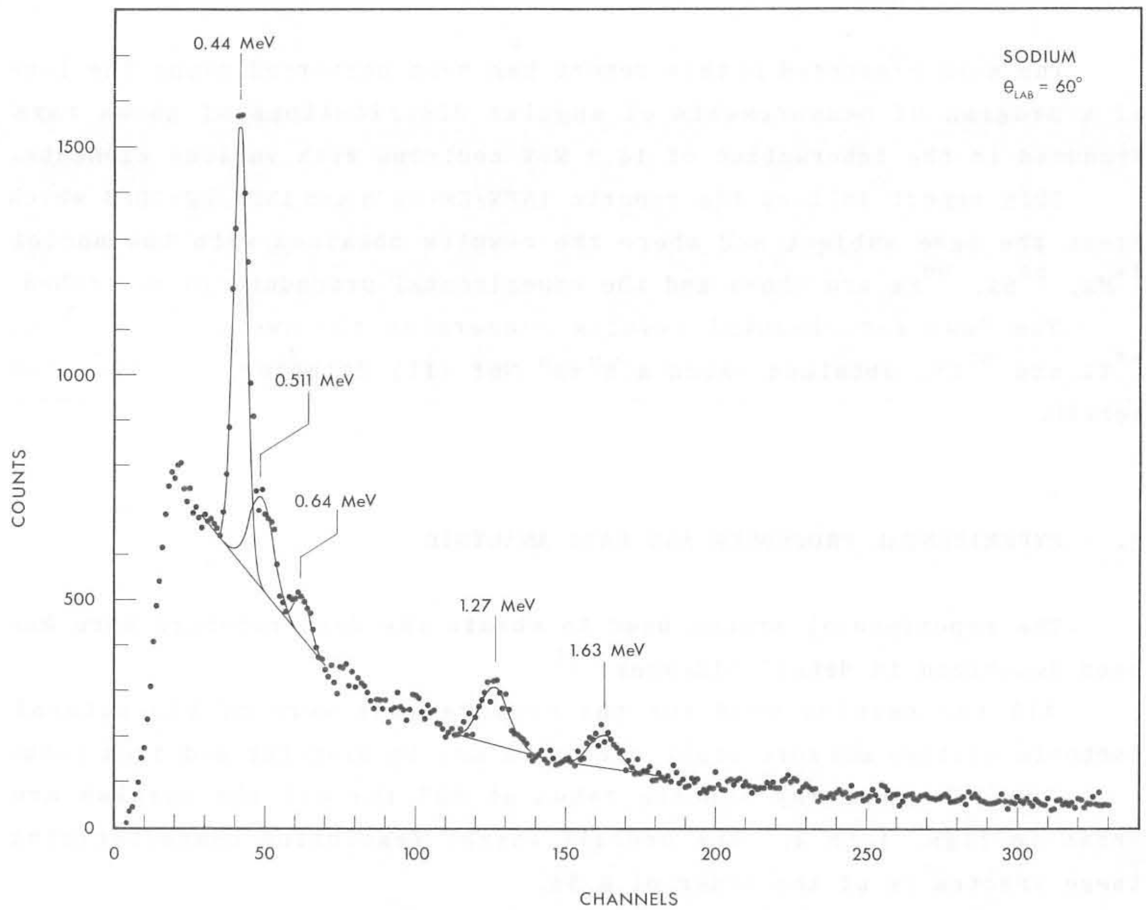

Fig. 1. - Typical gamma-ray pulse-height spectrum from natural sodium.

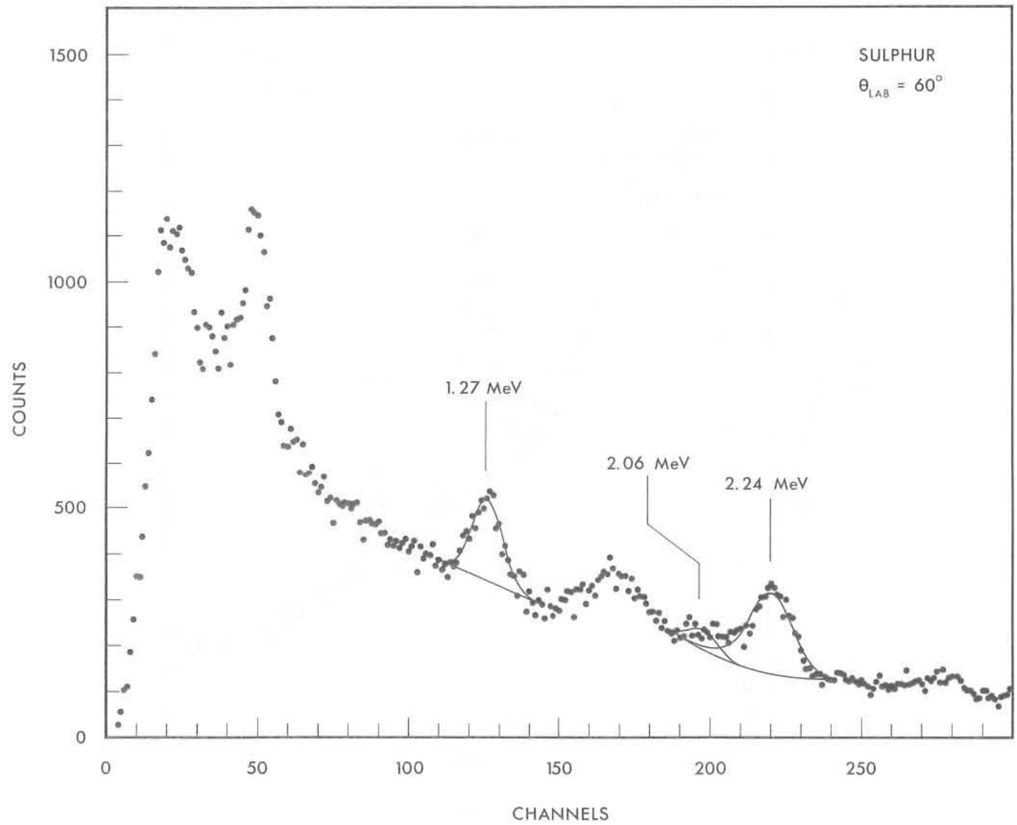

Fig. 2. - Typical gamma-ray pulse-height spectrum from natural sulphur.

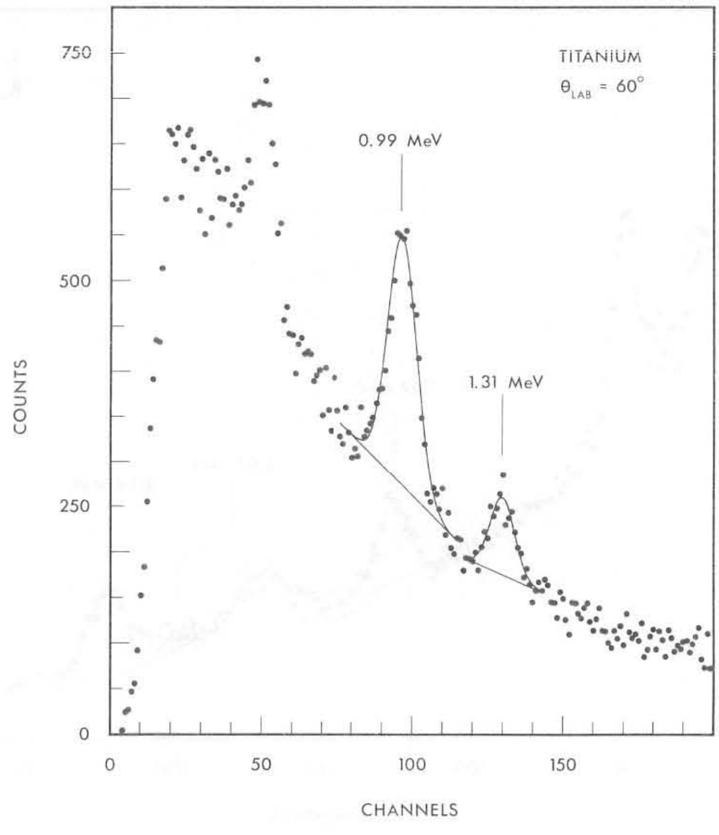

Fig. 3. - Typical gamma-ray pulse-height spectrum from natural titanium.

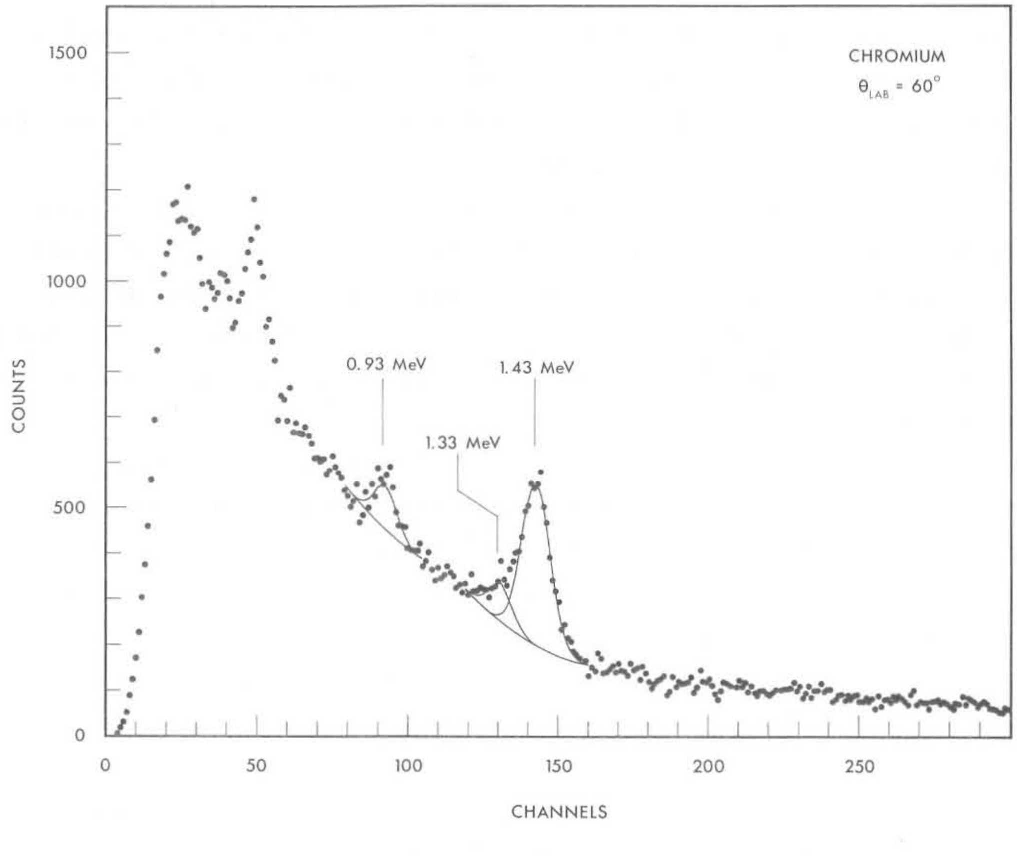

Fig. 4. - Typical gamma-ray pulse-height spectrum from natural chromium.

3. - RESULTS AND CONCLUSIONS

The observed gamma rays are listed in table 1.

The differential cross-section values are plotted in figs. 5 to 8.

The Legendre coefficients obtained for the least-squares fit to these distributions are given in table 2. They yielded the total cross-section values reported in the same table.

The gamma rays studied in this report are produced by the de-excitation of the residual nuclei left in an excited state in a nonelastic reaction of the type (n,x), where x can be a nucleon or several combinations of nucleons. Perhaps with the exception of a few cases, it is not possible to assign without any doubt anyone of the observed gamma rays to a definite nonelastic process.

In table 1 the reactions which are likely to be predominant in producing a nucleus emitting the observed gamma ray are proposed, together with the possible transition between two levels which gives that gamma ray. The relevant part of the nuclear-level schemes, derived from the compilation of ref. (4), required for illustrating these transitions, are shown in fig. 9.

Anyhow, it should be clear that other reactions and transitions in addition to those listed in table 1, probably involving the other isotopes which are present in the natural mixture of the samples used for the experiment, could be responsible for the production of the observed gamma rays; the list is limited to those reactions and transitions which can be conceived on the basis of the nuclear data presently available, and for the principal isotope.

Moreover, it has to be noticed that the cross-sections which are reported in table 2 are the production cross-sections for gamma rays, but they do not represent the excitation cross-sections of the nuclear levels because these can be excited directly or through cascade processes from higher levels.

For the sake of comparison, the total production cross-sections obtained by multiplying by 4π the cross-sections measured at 90° by Engesser and Thompson (5) are listed in table 2. The values of the total production cross-sections for the 0.44-MeV gamma ray from ^{23}Na and for the 2.24-MeV gamma ray from ^{32}S deduced by Martin and Stewart (6) are also reported. No other data concerning the total production cross--sections have been found in the literature.

The only angular distributions published in the literature are those of Martin and Stewart (6) for the 0.44-MeV gamma ray from ^{23}Na and for the 2.24-MeV gamma ray from ^{32}S. It should be noticed that in the case

Table 1. Gamma rays from 14.2 MeV neutron interactions with various nuclei

Nucleus	Gamma-ray energy E_γ (MeV)	Proposed reaction	Q-value (MeV)	Transition in final nucleus (Roman number denotes excited level, g. s. denotes ground state)
$^{23}_{11}$Na	0.44	^{23}Na(n,n')^{23}Na*	-0.44	I, $5/2^+$ → g.s., $3/2^+$
	0.64	^{23}Na(n,n')^{23}Na*	-2.71	VI, $7/2^+$ → II, $7/2^+$
		^{23}Na(n,α)^{20}F*	-4.52	I, $(2,3^+)$ → g.s., 2^+
	1.27	^{23}Na(n,d)^{22}Ne*	-7.84	I, 2^+ → g.s., 0^+
		^{23}Na(n,α)^{20}F*	-5.92	VIII, (+) → II, (+)
	1.63	^{23}Na(n,n')^{23}Na*	-2.08	II, $7/2^+$ → I, $5/2^+$
$^{32}_{16}$S	1.27	^{32}S(n,α)^{29}Si*	+0.25	I, $3/2^+$ → g.s., $1/2^+$
		^{32}S(n,d)^{31}P*	-7.91	II, $3/2^+$ → g.s., $1/2^+$
	2.06	^{32}S(n,n')^{32}S*	-4.29	III, 2^+ → I, 2^+
		^{32}S(n,α)^{29}Si*	-0.50	II, $5/2^+$ → g.s., $1/2^+$
	2.24	^{32}S(n,n')^{32}S*	-2.24	I, 2^+ → g.s., 0^+
		^{32}S(n,d)^{31}P*	-8.87	III, $5/2^+$ → g.s., $1/2^+$
$^{48}_{22}$Ti	0.99	^{48}Ti(n,n')^{48}Ti*	-0.98	I, 2^+ → g.s., 0^+
	1.31	^{48}Ti(n,n')^{48}Ti*	-2.29	II, 4^+ → I, 2^+
$^{52}_{24}$Cr	0.93	^{52}Cr(n,n')^{52}Cr*	-2.37	II, 4^+ → I, 2^+
		^{52}Cr(n,d)^{51}V*	-9.21	II, $3/2^-$ → g.s., $7/2^-$
	1.33	^{52}Cr(n,n')^{52}Cr*	-2.76	IV, 4^+ → I, 2^+
	1.44	^{52}Cr(n,n')^{52}Cr*	-1.43	I, 2^+ → g.s., 0^+

Table 2. - Legendre coefficients and total production cross-sections of gamma rays from nonelastic processes.

$$\frac{d\sigma}{d\Omega} = a_0 + a_2P_2 + a_4P_4$$

Nucleus	E_γ (MeV)	a_o	a_2	a_4	$\sigma_{n,G}(E_\gamma)$ (mb) a)	Results of others (mb)
^{23}Na	0.44	35.06	-1.324	0.361	440±37	496 b); 463±56 c)
	0.64	5.086	-1.110	-0.102	64±12	80 b)
	1.27	15.76	2.164	-2.590	198±23	183 b)
	1.63	13.24	-2.492	1.780	166±23	236 b)
^{32}S	1.27	14.23	-4.455	-1.814	179±21	113 b)
	2.06	9.165	3.021	-0.739	115±26	
	2.24	22.17	2.880	-1.973	278±43	192 b); 332±50 c)
^{48}Ti	0.99	75.79	23.11	-7.727	952±86	652 b)
	1.31	33.68	3.338	-16.56	423±78	216 b)
^{52}Cr	0.93	17.59	6.682	2.707	221±31	
	1.33	19.01	9.048	4.737	239±36	
	1.43	60.29	10.45	-4.678	757±56	

a) The total production cross-section of gamma rays from nonelastic processes is indicated with the notation $\sigma_{n,G}(E_\gamma)$ as recommended by CINDA (7).

b) Obtained by multiplying by 4π the differential cross-section for 14.7 MeV neutrons measured at 90°, and reported in Ref. (5)

c) Total production cross-section for 14.1 MeV neutrons given in Ref. (6)

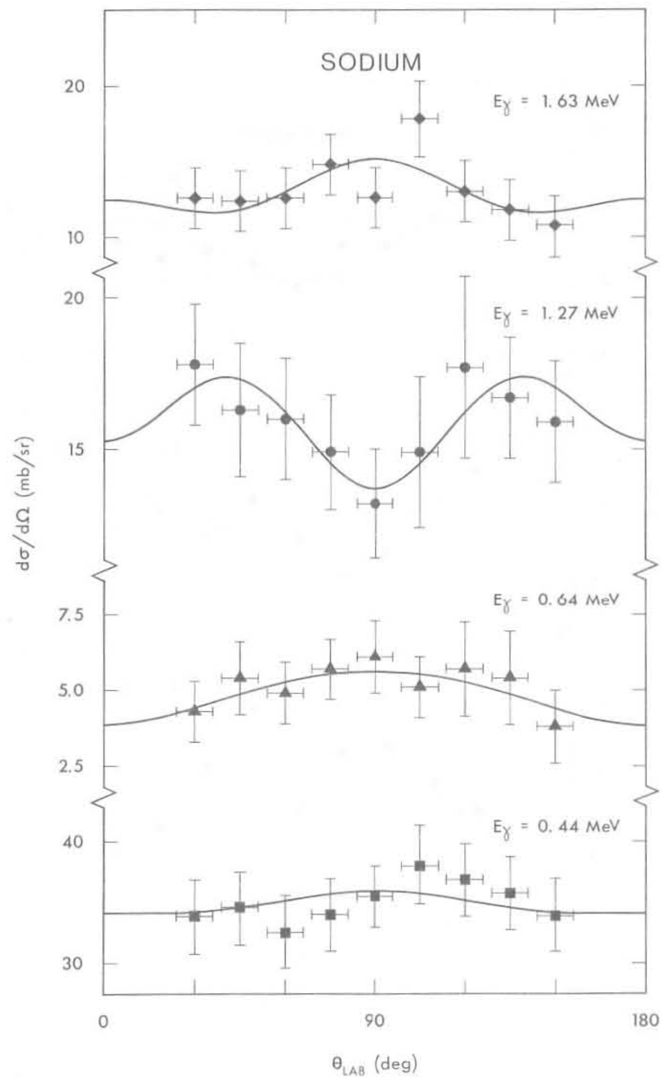

Fig. 5. - The angular distributions for the 0.44-, 0.64-, 1.27-, 1.63-MeV gamma rays from sodium.

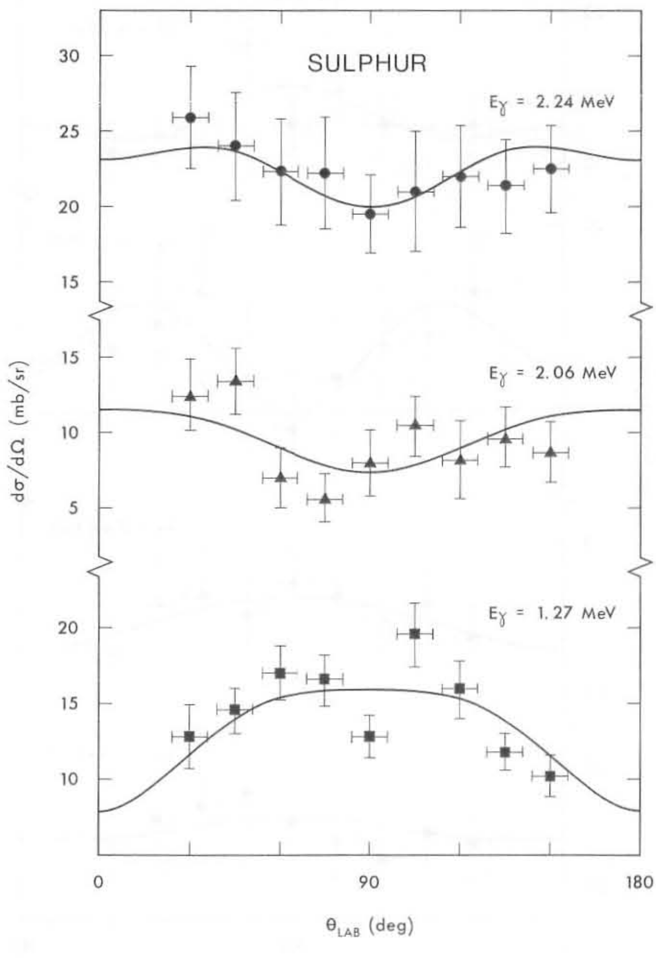

Fig. 6.--The angular distributions for the 1.27-, 2.06-, 2.24- MeV gamma rays from sulphur.

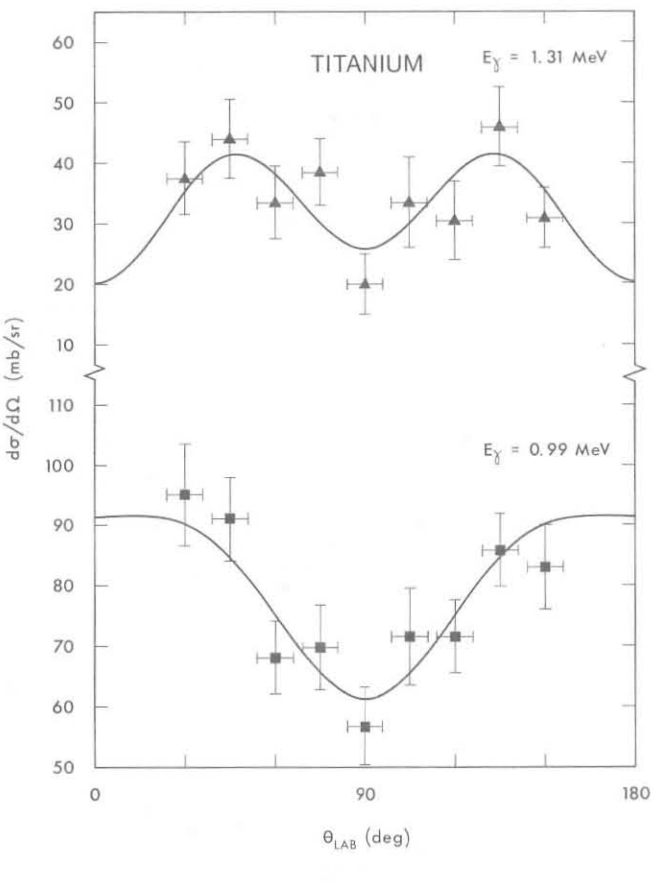

Fig. 7. - The angular distributions for the 0.99- and 1.31- MeV gamma rays from titanium.

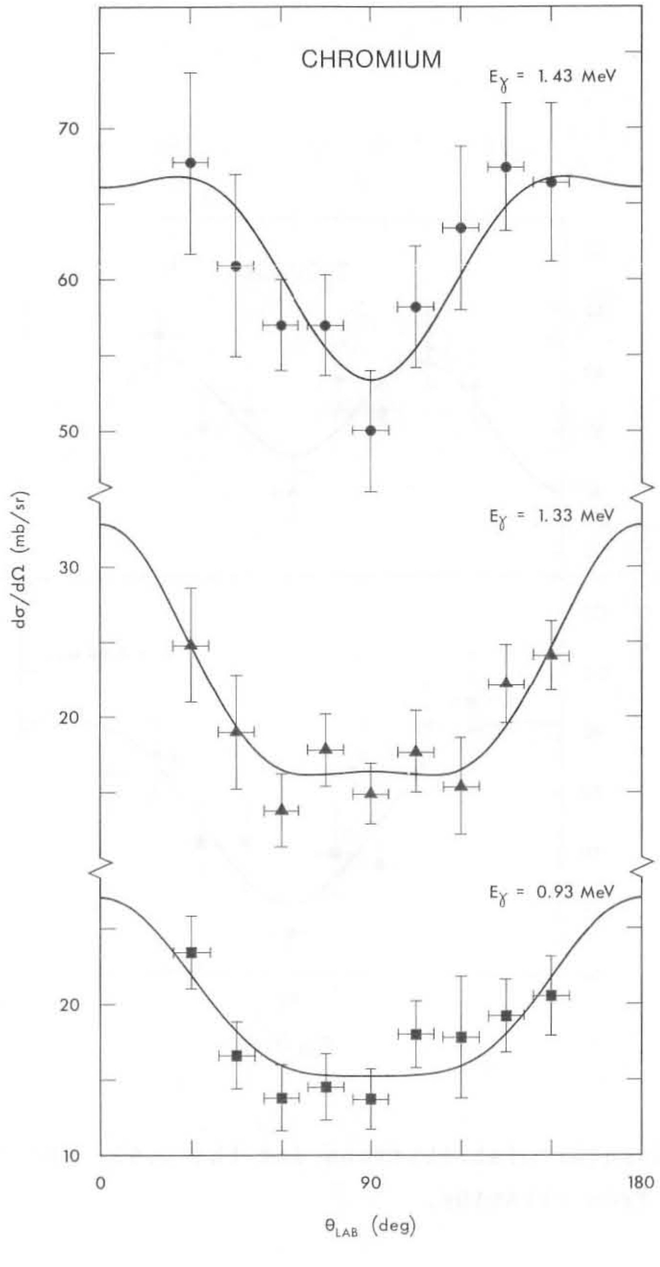

Fig. 8. - The angular distributions for the 0.93-, 1.33-, 1.43- MeV gamma rays from chromium.

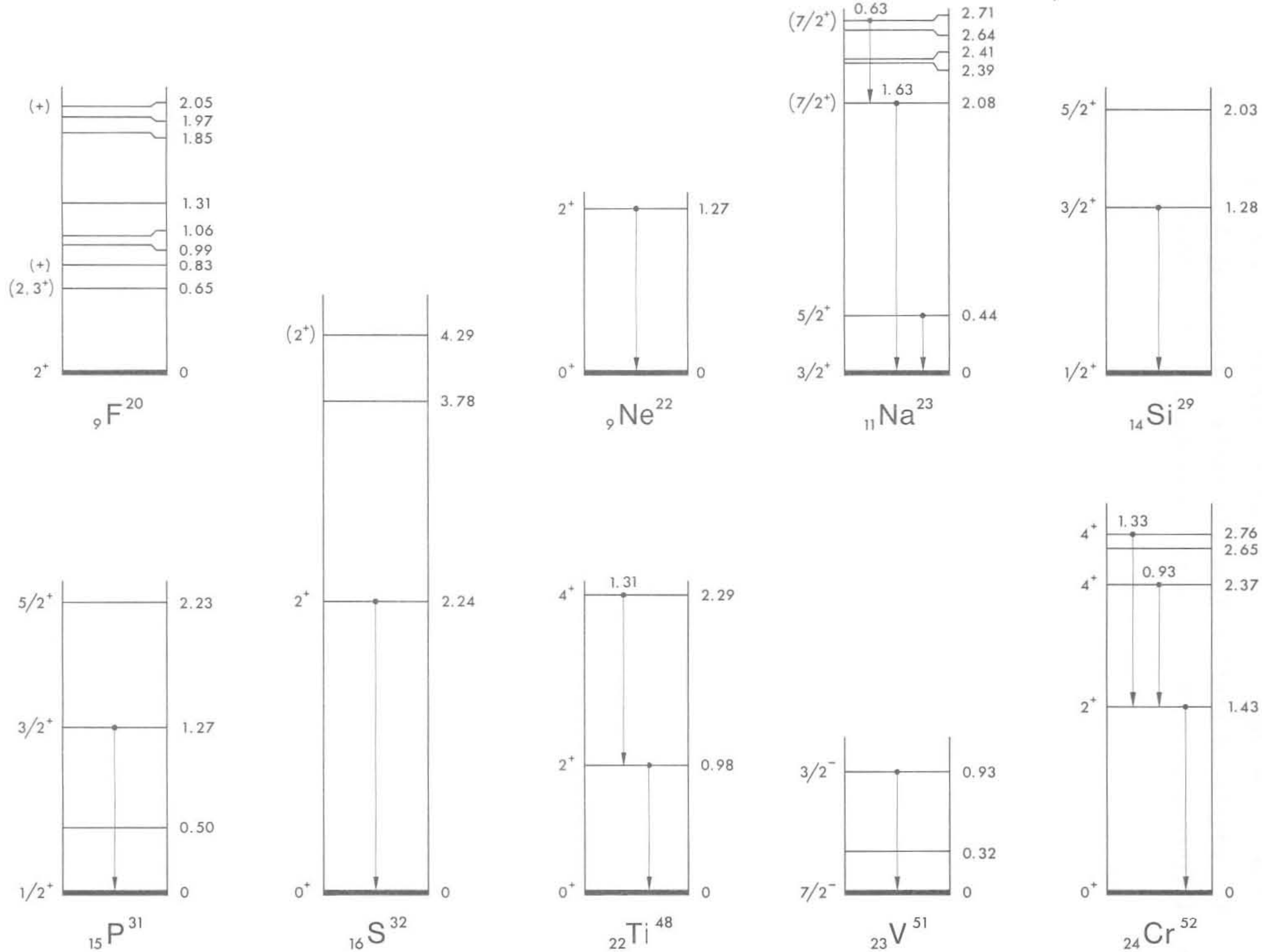

Fig. 9. - Nuclear level schemes of the ^{20}F, ^{22}Ne, ^{23}Na, ^{29}Si, ^{31}P, ^{32}S, ^{48}Ti, ^{51}V and ^{52}Cr nuclei for the low energy levels concerned with in this report.

of the 0.44-MeV transition of ^{23}Na the results of Martin and Stewart seem to indicate some isotropy in the angular distributions while the results presented in this report do not. Moreover, the differential cross-sections given by Martin and Stewart for the 2.24-MeV gamma ray from ^{32}S are smaller at small angles amd rather greater at large angles, than the differential cross-sections presented in this report.

The authors should like to acknowledge the interest shown in this work by Professor G. Poiani.

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