ENERGY LEVELS OF Sc^{45} AND Ca^{42} *

NIVELES DE ENERGIA DE Sc^{45} y Ca^{42}

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RESUMEN

Los espectros de las reacciones $Sc^{45}(p,p')$ y $Sc^{45}(p,\alpha)Ca^{42}$, fueron estudiados con un espectrógrafo magnético de alta resolución con ángulos de 50°, 90° y 130° respecto a la dirección del haz de proyectiles.

Los protones incidentes con energías de 6.52 Mev fueron obtenidos empleando el Acelerador Electrostático MIT-ONR.

Estados excitados de Sc^{45} se asociaron a los grupos de protones inelásticos observados en espectros como el mostrado en las Figs. a, b y c. La identi-

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ficación de los niveles pertenecientes a Sc^{45} o a otra sustancia se determinaron mediante sus corrimientos relativos característicos para los distintos ángulos de observación, asi como la exploración de las zonas cubiertas por grupos intensos debidos a impurezas en el blanco. El espectro nuclear de Sc^{45} quedó determinado basta una energía de excitación de 3.54 Mev. Los niveles correspondientes se han ordenado en la Tabla I y en la Fig. 2; los niveles 8 y 44 resultaron de una anchura mayor que los restantes, probablemente integrados por grupos próximos no resueltos. En la tabla citada se incluye la información publicada por el Instituto Rice.

Un estado excitado del Cl^{35} quedó definitivamente establecido en 3.163 ±0.005 Mev en estos estudios, dado a conocer como dato inseguro en experimentos anteriores, observando los protones inelásticos del Cl^{35}

La comparación entre los valores de los niveles de energía observados en reacciones Ca^{42} (p,p') y $Sc^{45}(p,\alpha)$ Ca^{42}, muestra una semejanza muy estrecha como puede comprobarse en la Tabla II; en la reacción $Sc^{45}(p,\alpha)$ Ca^{42} aparece un nivel de excitación de Ca^{42} de 3.191 ± 0.008 Mev, no observado en los primeros experimentos, probablemente por el alto fondo que se tenía en esas exposiciones.

El valor Qo = 2.341 ± 0.008 Mev, correspondiente al estado base de la reacción $Sc^{45}(d,\alpha)$ Ca^{42}, resulta esta vez muy próximo al estimado con las masas de estos mismos elementos, medidas espectroscópicamente. Otros resultados obtenidos por este laboratorio que pertenecen a elementos de la misma región de la tabla periódica, cotejados por ambos métodos, exhiben discrepancias más notables.

I. INTRODUCTION

The stable nucleus of mass number 45 is an isotope of scandium. Relatively little is known regarding the excited states of this nucleus [1]. Windham et al[2] have studied inellastic proton scattering from Sc^{45} and have reported several levels in the region of excitation between the ground state and 1.66 Mev. The low lying levels they report are not confirmed by studies of $Sc^{45}(\alpha, \alpha' \gamma)$ nor have any gamma rays been observed in the positron decay of Ti^{45}.

The $Sc^{45}(p,\alpha) Ca^{42}$ reaction has not been observed in previous work. The ground state Q value for this reaction would supply an important link between the masses in this region of the periodic table. The excited states of Ca^{42} have been studied through the $K^{39}(\alpha,p) Ca^{42}$ and $Ca^{42}(p,p') Ca^{42}$ reactions and a number of levels are known up to an energy of 4 Mev. The results have been summarized in an article by Endt and Braams[3].

The work reported here was undertaken as an investigation of the Sc^{45} level scheme and to determine the Q-value for the $Sc^{45}(p,\alpha) Ca^{42}$ reaction.

II. EXPERIMENTAL PROCEDURE

The essential equipment used in these experiments consisted of the MIT-ONR electrostatic accelerator[4] and a 50 cm. broad-range magnetic spectrograph[5]. The accelerator provided a proton beam of 6.52 Mev and the spectrograph was used to analyze the charged particle spectrum at several angles of observation. The energy resolution for the incident beam was approximately .05 percent. The resolving power of the spectrograph was limited by the energy spread in the bombarding beam and by the target thickness to approximately 1000. The general experimental techniques resembled those recently described by Mazari et al[6] in a report on the 40 cm. spectrograph at the National University of Mexico and in a publication[7] on a similar investigation of the excited states of Co^{59} and Fe^{56}.

The targets were prepared by the evaporation in vacuum of scandium oxide and metallic scandium. We are indebted to Dr. F.H. Spedding of the Iowa State College and Dr. F.J. Hill of Los Alamos Scientific Laboratories, for supplying us with the metal. Tantalum boats were used in the evaporation procedure and the vaporized material was collected on thin Formvar films supported on wire frames. The resulting Sc targets had thicknesses of about 5 Kev for 6.5 Mev protons. These targets were fragile and tended to break under bombardment. For this reason, they were mounted in a mechanism in the target chamber which moved them in such a way that the bombarded area was a ring shaped region rather than the concentrated spot of approximately 3/4 x 2 mm which would have been the case had the targets been stationary.

Natural scandium consists of the single isotope of mass number 45. This considerably simplified the problem of identifying the origns of the observed particle groups. The identification was made on the basis of their characteristic shifts in energy with the angle of observation. Exposures of the order of 1500 microcoulombs were made at angles of 50, 90, and 130 degrees. In each case the incident energy was within a few kilovolts of 6.52 Mev and was determined precisely from the elastically scattered protons from scandium and the various contaminants such as carbon and oxygen present in the targets. In the 50 degree exposure the target was oriented so that the observed particles had passed through the Formvar film. At the other angles, the scandium layer faced both the beam and the spectrograph aperture.

III. RESULTS

Figures 1 a, b y c show a typical proton spectrum obtained during these experiments. The groups which originated in the materials of the Formvar and in the impurities of the target are labelled with their chemical symbols. The other groups, which are numbered from 1 through 48, are associated with excited states in Sc^{45}. In the particular exposure for Figures 1 a, b y c which was taken at 50 degrees, the group marked 1 was on the low energy tail of the intense group due to elastic scattering from C^{12} and the region between it and the elastically scattered group from Sc^{45} is to a large extent obscured by other elastic groups. That there were no groups in this region associated with Sc^{45} was ascertained in the other exposures at larger angles.

The positions of the excited states in Sc^{45} as determined in the present work are listed in Table 1. Except for levels number 8 and 44, for which the associated groups were wider than others in the same region of the spectrum, all the levels were single within the resolution used. Numbers 8 and 44 may consist of two or more closely spaced states. The excitation energies listed are the averages of the values obtained from the various exposures. Except for levels 4 and 7 which were obscured by contaminants in the 130 degree exposure, all the associated groups through number 44 were observed at each of the angles at which observations were made. The values for levels 45, 46, 47 and 48 were obtained from the 50 and 90 degree exposures. In no case did the value from any individual measurement differ by more than 3 kilo electron volts from the averages listed. Figure 2 is an energy level diagram for Sc^{45}, based on the present results.

Also included in Table 1 are the previously mentioned results from the Rice Institute[2]. The agreement in nearly all cases is excellent. Two of the levels they reported, at .860 and 1.06 Mev, were not conclusively identified and we have found no evidence for the former. That they did not observe levels 4, 8 and 11 may be ascribed to the somewhat lower bombarding energy used in their investigation and to the fact that their angle of observation was limited to 180°. The targets used had a considerable contamination of chlorine and a number of groups associated with inellastic scattering from Cl^{35} were observed. The excitation energies of the corresponding states were in excellent agreement with previous results on this nucleus[8]. In this previous study of Cl^{35}(p,p'), a probable level at 3.165 Mev was listed but was not conclusively identified. In the present work, we have seen a group, corresponding to an excitation energy in Cl^{35} at 3.163 ± 0.005 Mev, at 50, 90 and 130° and the close agreement

ENERGY LEVELS FROM THE Sc^{45}(p,p') REACTION

Level	Ex (Mev)	Rice Institute[2]	Level	Ex (Mev)
1	0.376 ± 0.004	0.377 ± 0.003	25	2.599 ± 0.005
2	0.540 ± 0.004	0.541 ± 0.003	26	2.719 ± 0.005
3	0.719 ± 0.004	0.722 ± 0.005 0.860	27	2.750 ± 0.005
4	0.936 ± 0.004		28	2.779 ± 0.005
5	0.974 ± 0.004	0.972 ± 0.004	29	2.893 ± 0.005
6	1.065 ± 0.004	1.06	30	2.907 ± 0.005
7	1.236 ± 0.004	1.235 ± 0.005	31	2.944 ± 0.005
8	1.299 ± 0.005*		32	2.960 ± 0.005
9	1.408 ± 0.005	1.409 ± 0.005	33	2.983 ± 0.005
10	1.433 ± 0.005	1.432 ± 0.005	34	3.025 ± 0.005
11	1.555 ± 0.005		35	3.068 ± 0.005
12	1.661 ± 0.005	1.661 ± 0.005	36	3.090 ± 0.005
13	1.799 ± 0.005		37	3.115 ± 0.005
14	2.030 ± 0.005		38	3.136 ± 0.005
15	2.091 ± 0.005		39	3.164 ± 0.005
16	2.106 ± 0.005		40	3.177 ± 0.005
17	2.223 ± 0.005		41	3.286 ± 0.005
18	2.291 ± 0.005		42	3.346 ± 0.005
19	2.303 ± 0.005		43	3.362 ± 0.005
20	2.341 ± 0.005		44	3.412 ± 0.005 *
21	2.351 ± 0.005		45	3.447 ± 0.005
22	2.531 ± 0.005		46	3.463 ± 0.005
23	2.562 ± 0.005		47	3.512 ± 0.005
24	2.590 ± 0.005		48	3.539 ± 0.005

* Probable double levels

TABLE 1

between the Q-values measured at these angles indicates that this assignment is correct. There was also a considerable amount of tantalum in the targets and inelastic scattering associated with excitation of the well-known state, measured here at 0.135 ± 0.006 Mev, was observed.

Because in the 50° exposure the alpha particles passed through the target before entering the spectrograph, Q-values associated with the $Sc^{45}(p,\alpha)Ca^{42}$ reaction were calculated from the 90 and 130 degree observations. That the highest energy group observed corresponded to the ground state transition was assured by the excellent agreement between the energies for the excited states in Ca^{42}, calculated on this assumption from the other lower energy groups and the values obtained by Braams[9] from inelastic proton scattering studies on Ca^{42}. The ground state Q value for this reaction was found to be 2.341 ± 0.008 Mev. This Q value can also be calculated from the masses of Sc^{45} and Ca^{42} as determined by Giese and Benson[10]. Using the mass excesses for H^1 and He^4 adopted by these authors, the mass spectroscopic Q value is 2.343 Mev. The agreement is somewhat better that has generally been found between the two methods in this region of the mass table.

EXCITED STATES IN Ca^{42} FROM THE $Sc^{45}(p,\alpha)Ca^{42}$ REACTION

Qo = 2.341 ± 0.003 Mev

Level	Ex (Mev)	M.I.T.[9] $Ca^{42}(p,p')Ca^{42}$
1	1.526 ± 0.006	1.523 ± 0.004
2	1.836 ± 0.006	1.836 ± 0.004
3	2.425 ± 0.006	2.422 ± 0.005
4	2.753 ± 0.006	2.750 ± 0.005
5	3.191 ± 0.008	Not observed
6	3.255 ± 0.008	3.250 ± 0.006

TABLE II

The energies of the excited states in Ca^{42} determined in the present work are listed in Table II, together with the results of Braams[9]. The values from the (p,α) studies are the averages of the determinations at 90 and 130 degrees, the maximum deviations of the individual measurements from the listed averages being 4 Kev or less except for level 2 for which the corresponding groups in the 90° exposure was obscured by a contaminant peak. The value for this level is based on a single observation. It is perhaps not surprising that the state at 3.191 Mev was not seen in the inelastic proton scattering studies. These were carried out with the same equipment used in the present work but at a time when a high background from various sources tended to obscure groups of low intensity. Aside from this discrepancy the results from the (p,α) reaction confirm the values given by Braams.

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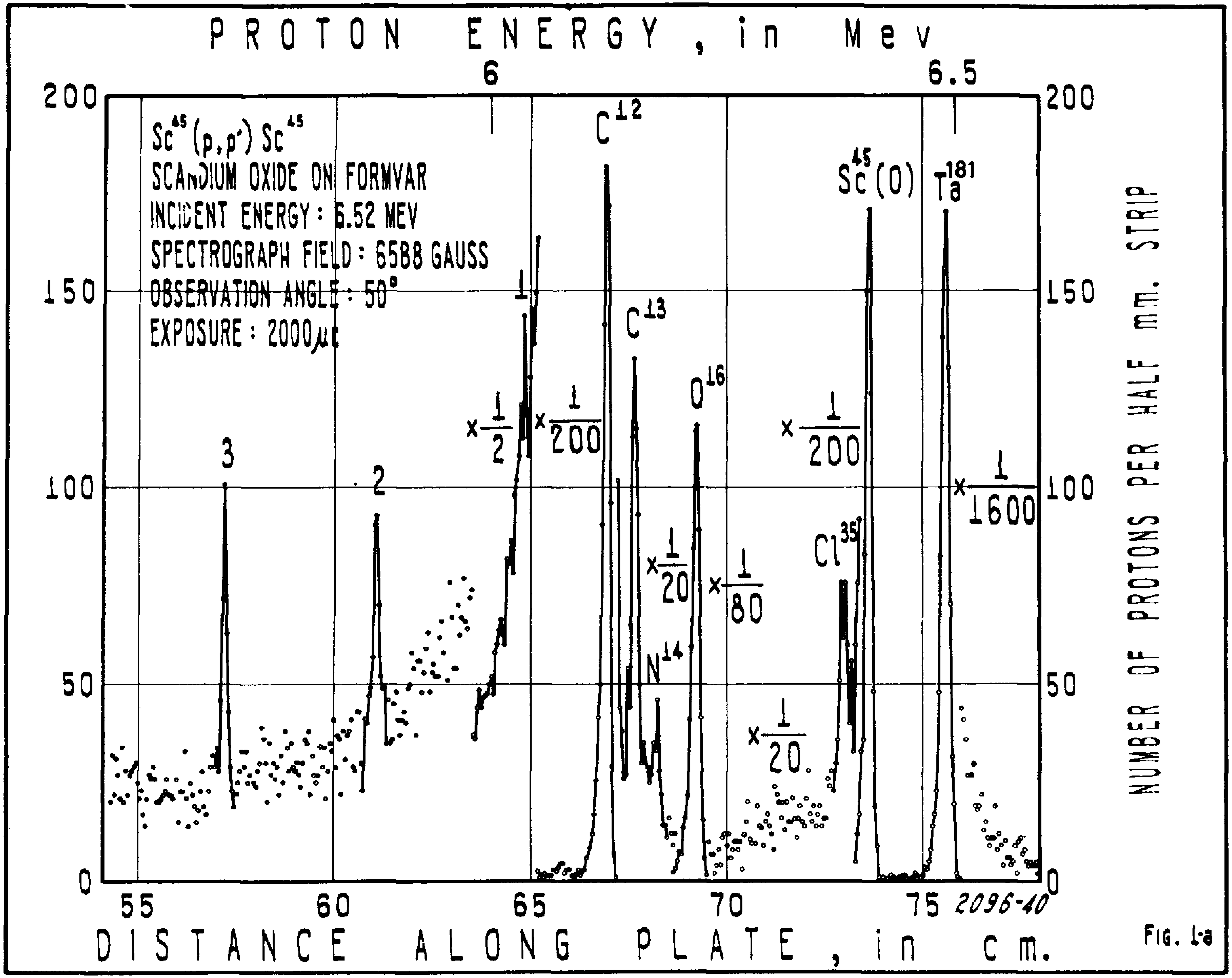
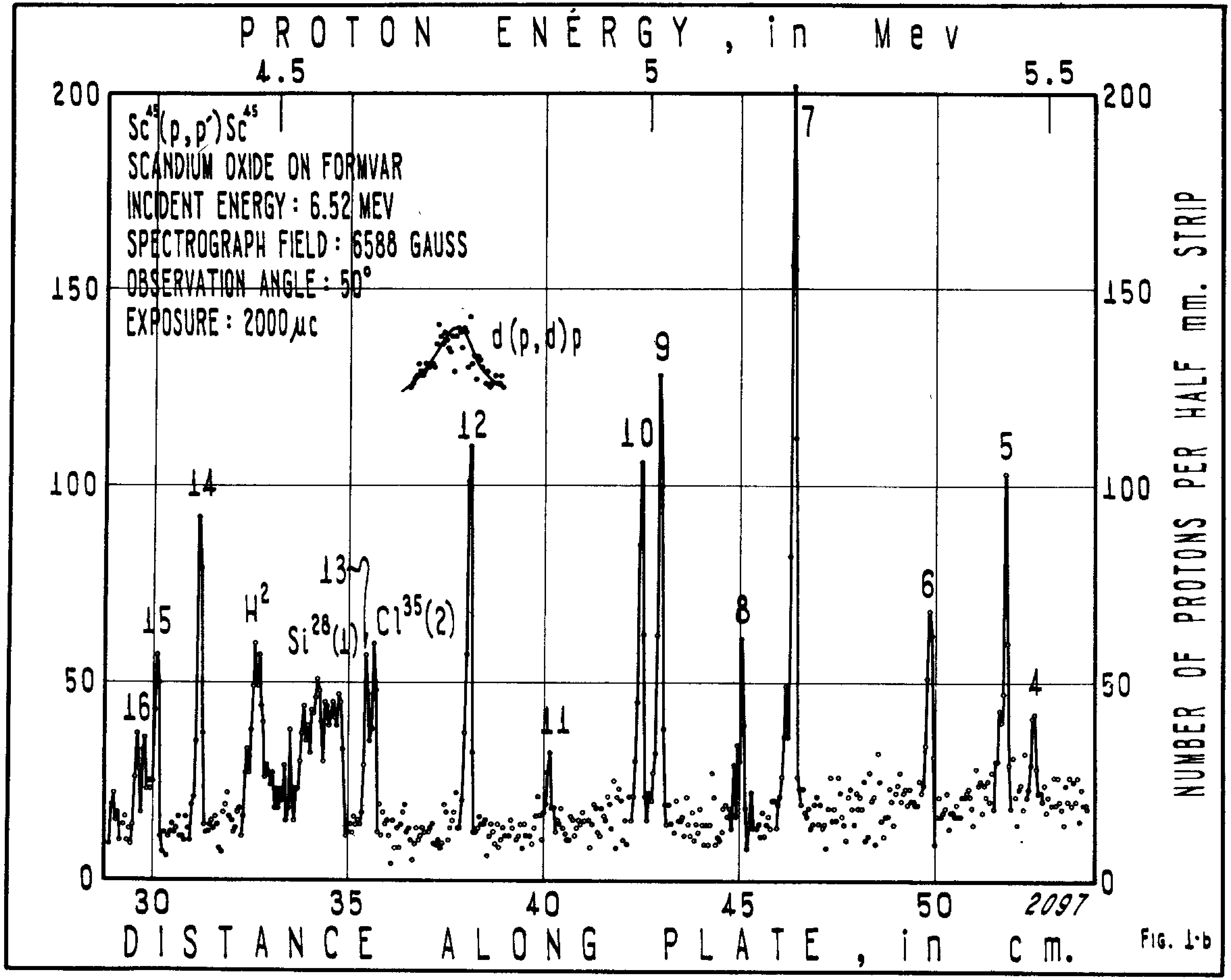


FIG. 1-a

PROTON SPECTRUM FROM A THIN SCANDIUM TARGET.



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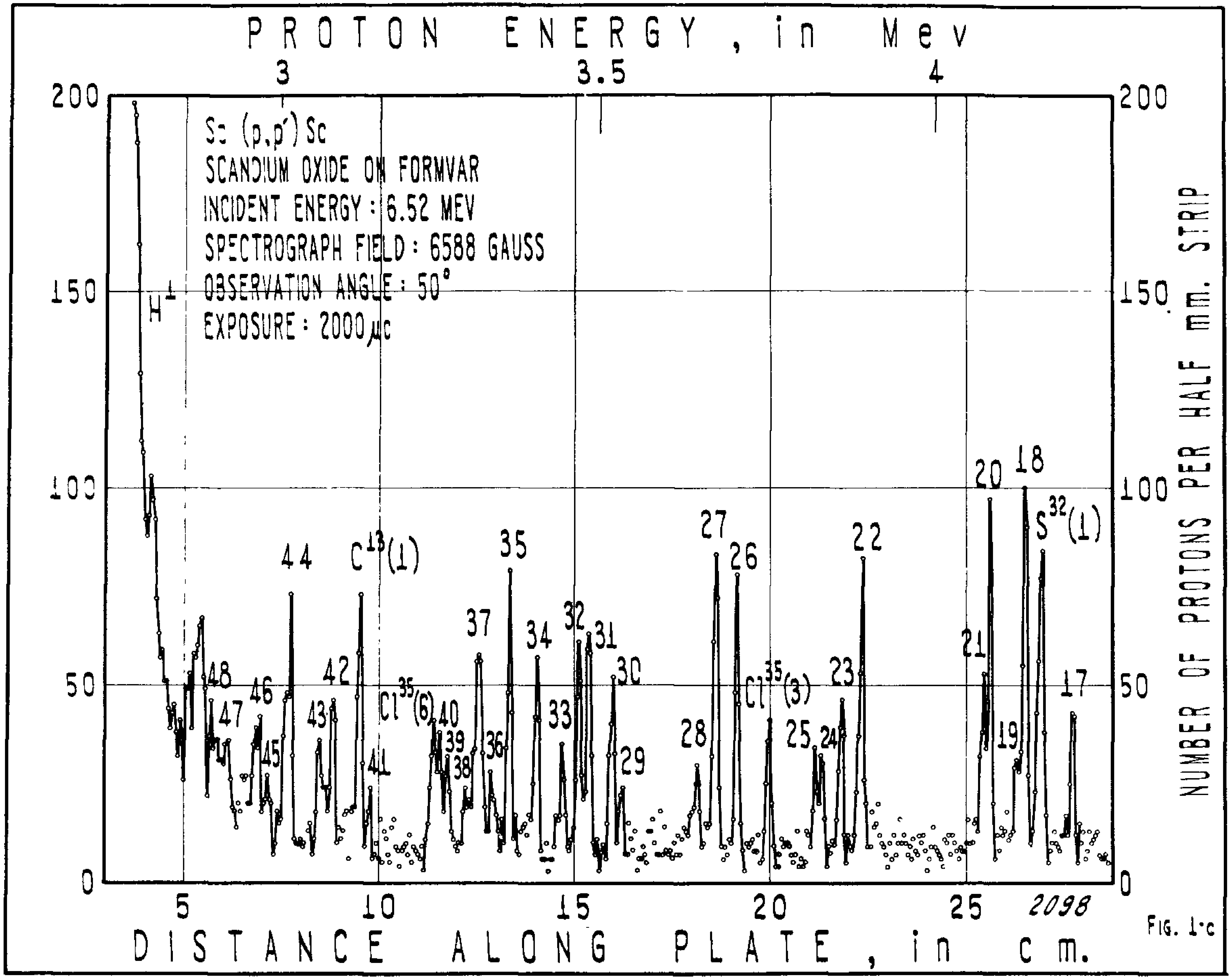

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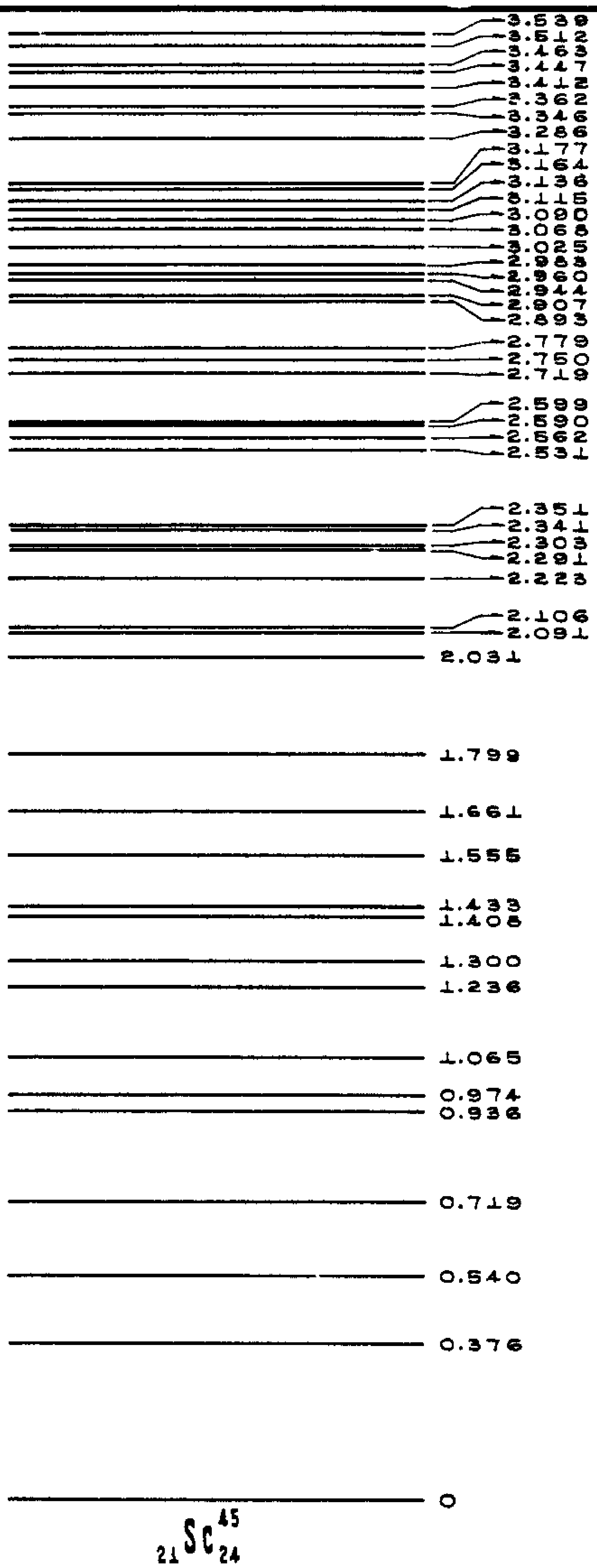

ENERGY LEVEL DIAGRAM OF Sc^{45}

Fig. 2