ENERGY LEVELS IN ^{46}Sc FROM THE $^{45}Sc(d,p)^{46}Sc$ REACTION

NIVELES DE ENERGIA EN ^{46}Sc OBTENIDOS A TRAVES DE LA REACCION $^{45}Sc(d,p)^{46}Sc$

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RESUMEN

Muy poco se conoce de los espectros de los isótopos del escandio (^{40}Sc a ^{48}Sc). Con el advenimiento de los aceleradores Van de Graaff Tandem y a través de reacciones nucleares entre partículas cargadas se hace posible investigar con

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precisión las propiedades físicas de dichos núcleos. Solamente los espectros de ^{45}Sc *y* ^{46}Sc *han sido investigados en el Instituto Tecnológico de Massachusetts por medio de los procesos nucleares (p,p') y (d,p), respectivamente. Las técnicas experimentales empleadas en estos estudios ya han sido descritas en detalle con anterioridad*[1].

Bartholomew y Kinsey[3] *reportaron 8 rayos gamma, los que asignados a transiciones directas podrían corresponder a 7 posibles niveles en* ^{46}Sc *entre 0 y 2.5 MeV de excitación empleando reacciones (n,γ). Después del reporte preliminar de este trabajo*[2]*, otras medidas de rayos gamma fueron reportadas*[6]*. En el estudio presente 24 niveles fueron establecidos hasta la energía de excitación mencionada, 54 abarcando 3.94 MeV del espectro de* ^{46}Sc *y 70 niveles más no calculados en detalle entre los 4 y 7.6 MeV de excitación.*

Un ejemplo de los espectros obtenidos para la reacción $^{45}Sc(d,p)^{46}Sc$ *empleando una energía incidente de 6.5 MeV y observando los productos de reacción a* 30° *respecto a la dirección del haz de proyectiles, se muestra en la Fig. 1. Los resultados referentes a las energías de excitación de los diferentes niveles han sido ordenados en la tabla 1 y en la Fig. 2, en la que además se han incluido resultados de otros investigadores*[3,6] *con fines de comparación.*

El valor Q que liga los estados base de los núcleos ^{45}Sc *y* ^{46}Sc *a través de la reacción (d,p) resultó,* $Q_o = 6.541 \pm 0.008$ *MeV.*

INTRODUCTION

The element scandium with $Z = 21$ has only one stable isotope, ^{45}Sc. There exists little knowledge of the energy levels in the isotopes ranging form ^{40}Sc to ^{48}Sc. Due to a combination of limitations arising from experimental and kinematical considerations involving nuclei in the neighborhood of scandium, few charged particle reaction experiments have thus far been undertaken. With the use of higher energies from tandem accelerators and ^{3}He induced reactions on neighboring nuclei, some of these limitations may soon be removed and thus, in principle, make possible energy level studies for all the scandium isotopes.

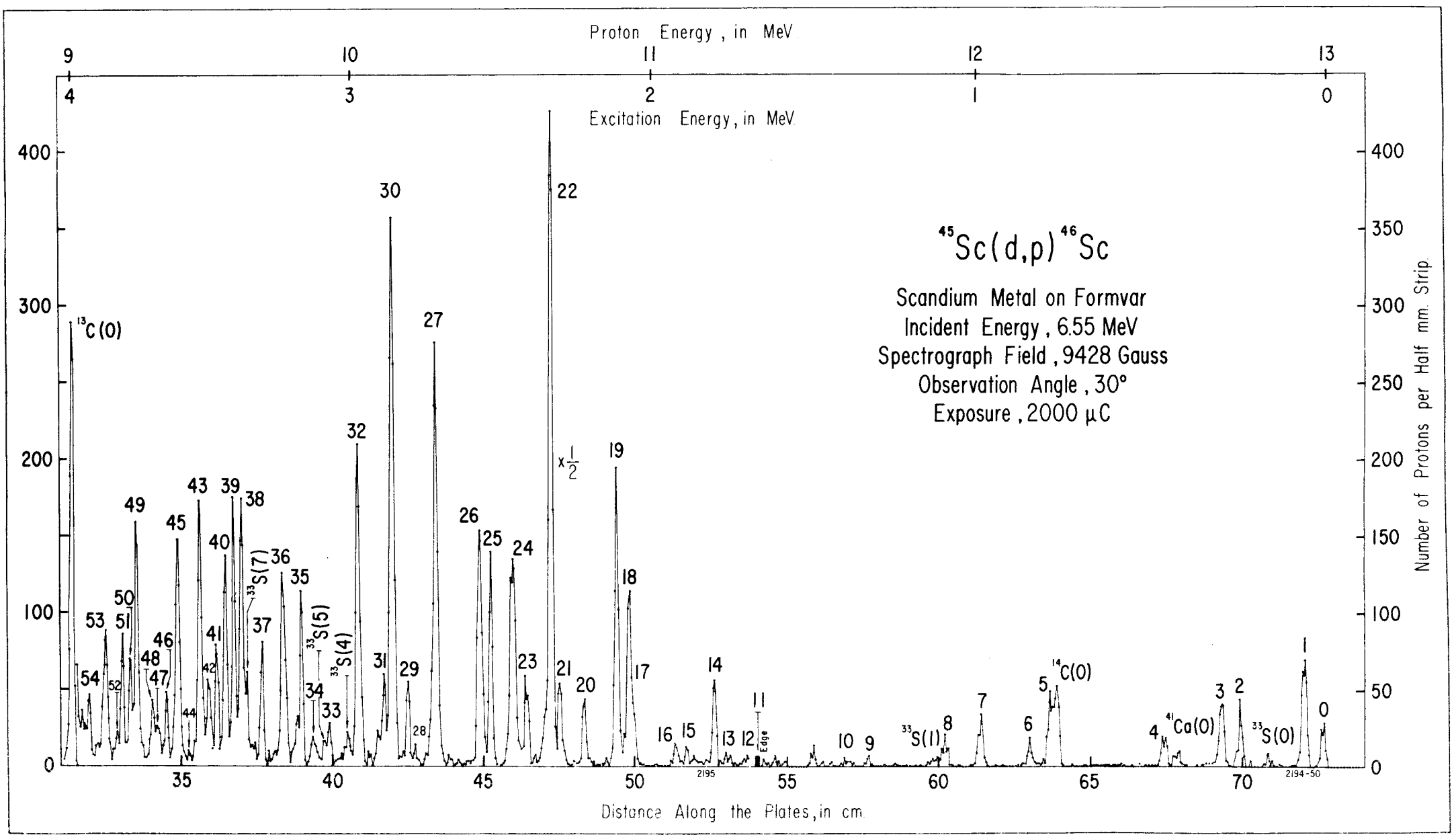
Proton Energy, in MeV
9
10
11
12
13
4
3
2
1
0
Excitation Energy, in MeV
$^{45}Sc(d,p)^{46}Sc$
Scandium Metal on Formvar
Incident Energy, 6.55 MeV
Spectrograph Field, 9428 Gauss
Observation Angle, 30°
Exposure, 2000 μC
$^{13}C(0)$
$^{33}S(7)$
$^{33}S(5)$
$^{33}S(4)$
$^{33}S(1)$
$^{14}C(0)$
$^{41}Ca(0)$
$^{33}S(0)$
x 1/2
Edge
2195
2194-50
Number of Protons per Half mm. Strip
Distance Along the Plates, in cm.

Fig. 1

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In this laboratory only the level schemes in ^{45}Sc and ^{46}Sc have thus far been investigated. Energy levels in ^{45}Sc up to 3.539 MeV through inelastic proton scattering from ^{45}Sc have been published[1]. The purpose of the present paper is to report the search of energy levels in ^{46}Sc from the (d,p) reaction on ^{45}Sc. Some of these results have already been reported[2] while the work was in progress. In the present paper, a more defailed information is given.

At the start of this work very little was known of the energy levels of ^{46}Sc. Bartholomew and Kinsey[3] had observed eight gamma rays following slow neutron capture in ^{45}Sc. If assigned to direct transitions from the capture state, these gamma rays would correspond to levels in ^{46}Sc at 2.50, 2.01, 1.70, 1.20, 0.67, 0.54 and 0.31 MeV with the highest energy gamma ray 8.85 ± 0.08 MeV perhaps going to the ground state. An isomeric state at 142 KeV has been observed and is well established[4]. Davidson[5] had reported two proton groups from the (d,p) reaction on ^{45}Sc and assigned one to a level in ^{46}Sc at 2.30 MeV and the other to the ground state transition with a Q-value of 6.78 ± 0.30 MeV. More recently and since the completion of this study, other workers have made more extensive measurements of the gamma rays from neutron capture experiments[6]. However, no other direct energy level study has been made. An objetive in the present work has also been to obtain a more precise measurement of the Q-value for the ground state transition of the ^{45}Sc (d,p) ^{46}Sc reaction which provides a mass link between both scandium isotopes.

EXPERIMENTAL RESULTS

The experimental technique used in the present investigation is essentially the same as that used in other charged particle reaction studies reported[1] by this laboratory. The MIT - ONR electrostatic accelerator was used to provide an incident deuteron beam with energy of 6.5 MeV. The same thin targets of scandium oxide and metallic scandium evaporated on to formvar backings were used, as those in the (p,p') experiments. These targets were of the order of 5 μg/cm^2. Observations and measurement of particle groups were made at four angles with respect to the incident beam direction, namely 20°, 30°, 40° and 50°. The single-gap broad-range magnetic spectrograph was used both for determining the energy of the incident particle and

Table I

$^{45}Sc(d,p)^{46}Sc$. $Q_o = 6.541 \pm 0.008$ MeV

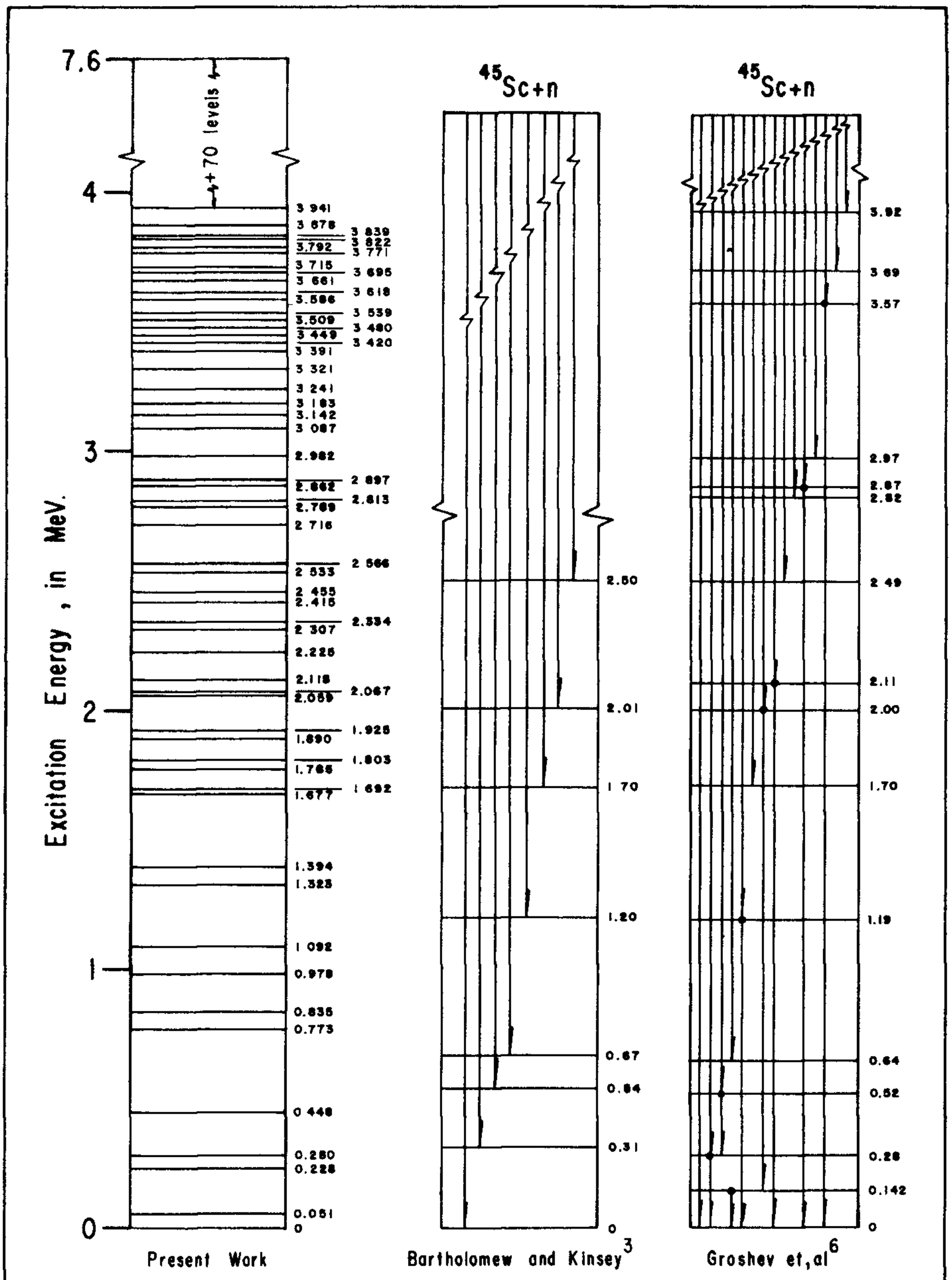
Level Nº	Ex. in MeV		Level Nº	Ex. in MeV	
1	0.051	±0.008	28	2.789	±0.012
2	0.228	"	29	2.813	"
3	0.280	"	30	2.862	"
4	0.448	"	31	2.897	"
5	0.773	"	32	2.982	"
6	0.835	±0.010	33	3.087	"
7	0.978	"	34	3.142	"
8	1.092	"	35	3.183	"
9	1.323	"	36	3.241	"
10	1.394	"	37	3.321	"
11	1.677	"	38	3.391	"
12	1.692	"	39	3.420	"
13	1.765	"	40	3.449	"
14	1.803	"	41	3.480	"
15	1.890	"	42	3.509	"
16	1.925	"	43	3.539	"
17	2.059	"	44	3.586	"
18	2.067	"	45	3.618	"
19	2.118	"	46	3.661	±0.015
20	2.225	"	47	3.695	"
21	2.307	"	48	3.715	"
22	2.334	"	49	3.771	"
23	2.415	"	50	3.792	"
24	2.455	±0.012	51	3.822	"
25	2.533	"	52	3.839	"
26	2.566	"	53	3.878	"
27	2.716	"	54	3.941	"

+ 70 levels up to an Ex. of 7.6 MeV

for analyzing the spectrum of protons from the (d,p) reaction on ^{45}Sc.

A spectrum of the reaction products observed at 30° is shown in Figure 1. Proton groups with energies ranging from 9.0 MeV to 13.0 MeV have been recorded in nuclear emulsions simultaneously during a single bombardment. The corresponding excitation energy in ^{45}Sc ranges from zero to 3.94 MeV. Analysis of this spectrum along with those obtained at 20°, 40° and 50° showed that except for a few groups from contaminant nuclei in the target, the majority of these groups resulted from the (d,p) reaction on ^{45}Sc. In addition to the usual contaminants of oxygen and carbon, small contributions from sulphur and calcium have been identified. That the level structure for ^{46}Sc should be so complex is not unexpected for an odd-odd nucleus. In the region up to about 2 MeV excitation, a number of well resolved but relatively weak groups are observed. Above about 2 MeV excitation, the intensity and density of groups appear to increase markedly. That part of the proton spectra below the $^{12}C(d,p)^{13}C(0)$ group (at extreme left edge of Fig. 1) and corresponding to an excitation in ^{46}Sc from 4.0 MeV to 7.6 MeV though recorded in these experiments, has not been analyzed in detail. The presence in this region of the carbon group along with the two peaks arising from the ground state transition and the first excited state of the $^{16}O(d,p)^{17}O$ reaction, has made difficult the positive assignment of ^{46}Sc groups above 4.0 MeV excitation.

In Table I, the energy levels assigned to the $^{45}Sc(d,p)^{46}Sc$ reaction are listed. A criterion for acceptance was that a particular group be observed at least on two of the four obtained spectra. In each case, the excitation energy listed is the average of the two (one case), three or four (most cases) individual measurements. The maximum deviation from the average value for a given group was 6 KeV. In a number of instances, weak proton groups were observed on only one of the four spectra. Some were obscured at other angles by contaminant peaks, while the presence of others were questioned either because of poor resolution or because of insufficient intensity above background. Between 4.0 MeV and 7.6 MeV excitation in ^{46}Sc, there were observed (though not computed) about 70 well defined and moderately intense groups due to scandium. The existence of many other perhaps weak or not resolved levels is suspected.



ENERGY LEVEL DIAGRAM OF ^{46}Sc.

Fig. 2

The highest energy group at a distance of 72.7 cm in Fig. 1, is attributed to the reaction of $^{45}Sc(d,p)^{46}Sc$ with a Q-value of 6.541 ± 0.008 MeV*.

Combining the value of 2.225 MeV for the deuteron binding energy with the highest energy neutron capture gamma ray observed by both Bartholomew and Kinsey and Groshev et al, the Q-values deduced for the $^{45}Sc(d,p)^{46}Sc$ reaction are 6.625 ± 0.080 MeV and 6.595 ± 0.050 MeV respectively. Both values are higher than the measured one in this experiment but considering the unusually large uncertainty in the gamma ray measurements, no statement of gross disagreement can be made. Combining the mass spectroscopic measurements[8] of the masses of ^{45}Sc and ^{46}Ti with the beta decay disintegration energy[9] for ^{46}Sc, a value of 6.544 ± 0.006 MeV for the Q-value of $^{45}Sc(d,p)^{46}Sc$ reaction is obtained, in excellent agreement with the present measurement, suggesting that the highest energy group measured in this work is indeed the ground state transition.

In Fig. 2 column one, an energy level diagram for ^{46}Sc shows the positions of the excited states determined in the present work. For purpose of comparison, in columns two and three, are shown the proposed energy level schemes from the (n,γ) measurements of Bartholomew and Kinsey, and Groshev et al, respectively.

The isomeric state at 0.142 MeV was not observed in this investigation presumably due to a low cross section usually associated with high spin states. In a recent study[10] of the angular distribution of proton groups from the $^{45}Sc(d,p)^{46}Sc$ reaction, there is evidence of the appearance of this level by the (d,p) process. With a deuteron bombarding energy of 7.0 MeV and at an angle of observation of 20° Rapaport indicates that the ratio of the group corresponding to the ground state transition to that of the isomeric state, is approximately 100.

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*This Q-value is based on the recently adopted[7] (1960) value of 5.3042 MeV for the energy of ^{210}Po alpha particles used at both the MIT and UNAM laboratories, as a calibration standard for the magnetic spectrographs. The value of 6.534 MeV reported earlier was based on a ^{210}Po alpha energy of 5.299 MeV.

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