THE ^{144}Sm(*d*, *t*) ^{143}Sm REACTION

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The levels of ^{143}Sm have been studied by means of the ^{144}Sm (d, t) reaction at bombarding energies of 12.1 MeV and 13.1 MeV. The reaction products were observed by a solid state counter telescope or by a magnetic spectrograph. Levels at 0 keV, 108 keV, 755 keV and 1104 keV were populated by the (d, t) reaction. The ground state Q-value was found to be — 4.262 MeV. Angular distribution measurements are in agreement with the shell model assignments $d_{3/2}, s_{1/2}, h_{11/2}$ and $d_{2/2}$, respectively, for the neutron hole states. The spectroscopic factors for these states were obtained from a DWBA calculation.

1. *Introduction*

Little is known about the level scheme of $^{143}_{62}$Sm. Decay scheme studies [1, 2, 3, 4] have revealed only one excited state at an excitation energy of 754 keV. The most likely origin of the 754 keV ray observed is the $h_{11/2-} \rightarrow d_{3/2+}$ transition in analogy with the other known M4 transitions in $N = 81$ nuclei. Such M4 transitions have been found in $^{133}_{52}$Te, $^{135}_{54}$Xe, $^{137}_{56}$Ba, $^{139}_{58}$Ce, $^{141}_{60}$Nd, $^{143}_{62}$Sm and $^{145}_{64}$Gd and they have all been ascribed to the transition $(11/2-) \rightarrow (3/2+)$. The energy of this transition has a regular Z-dependence and the lifetimes of most isomers are very nearly equal. The assignments of the $d_{3/2+}$ and $h_{11/2-}$ levels are therefore quite certain and in agreement with the shell model predictions for neutron hole states.

A study of the ^{144}Sm(d, t) reaction has never been reported before, but is of some interest as it leads to a nucleus with one hole in the $N = 82$ neutron shell.

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2. *Experimental procedure*

The 12.1 MeV and 13.1 MeV deuterons used in the experiments were obtained from the Niels Bohr Institute's Tandem accelerator. Samples of ^{144}Sm isotopically enriched to 94.5% were obtained as oxides from the Oak Ridge National Laboratory and reduced by lanthanum to samarium metal [6]. The ^{144}Sm metal was then evaporated in vacuum onto thin carbon foils. The target thickness was approximately 200 μg/cm^2. The triton angular distributions were measured by means of a solid state counter telescope consisting of a 50 μ thick ΔE counter and 200 μ thick E counter. The counters were operated in coincidence with the E signal gating the $E+\Delta E$ signal. This identification system was simpler to operate than the usual E, $\Delta E \times E$ system.

The $\Delta E+E$ system was thick enough to stop the 8 MeV tritons from the ^{144}Sm(d, t) reaction, but not to stop the highest energy protons and deuterons which had energy losses less than the expected triton energy. The α-particles produced from reactions on light elements in the target were completely stopped in the ΔE counter. For each angle the counter bias was adjusted to give optimum separation of the different kinds of particles, nevertheless for some angles the elastic deuteron groups from carbon and oxygen leaked through into the spectrum. The energy resolution in the triton spectra were from 35 keV to 50 keV, being somewhat dependent on scattering angle and counting rate.

The beam current was measured by a Faraday cup behind the target. The large background from elastically and inelastically scattered deuteron groups from ^{144}Sm, carbon, oxygen and other target impurities limited the angular range to from 50° until 160°. It was only possible to obtain angular distributions for the ground state and for the level at 108 keV excitation.

The measurements were continued in a single gap magnetic spectrograph [5] with photographic plate recording. The magnetic spectrograph was used for more precise Q-value and cross-section determinations and also to check the counter telescope measurements.

The magnetic spectrograph measurements were complicated due to the large negative Q-value for the ^{144}Sm(d, t) reaction. At a deuteron bombarding energy of 12 MeV the triton spectrum occurs in the same region of the photographic plate as the deuteron spectrum. To distinguish the deuteron tracks from the triton tracks an energy degrader made from Al foils was placed in front of the photographic plate. Thereby the energy of the tritons was reduced enough to make them terminate in the emulsion whereas the deuterons went through. An additional identification was made by considering the different energy shifts with angle for the deuteron and the triton groups. The total charge for each exposure was measured by a Faraday cup. The target was left in the same position for all angles and the absolute cross-sections at 90°, 125° and 150° for 12.1 MeV deuterons were obtained by normalization to elastic cross-sections of 40.0 mb/sr, 8.5 mb/sr and 6 mb/sr, respectively. At 150° and a deuteron energy of 13.1 MeV an elastic cross-section of 3.1 mb/sr was used for normalization. These elastic cross-sections were determined in a separate experiment in which the angular distribution of the elastic peak was measured at deuteron energies of 13.1 MeV, 12.1 MeV and 6.0 MeV. The absolute elastic cross-sections at 13.1 MeV and 12.1 MeV were then obtained by normalization to the Rutherford cross-section at 6.0 MeV.

3. Experimental results and discussion

Examples of spectra observed at 150° by means of the magnetic spectrograph and at 100° by means of the solid-state counter telescope are shown in Fig. 1. The angular distributions are presented in Fig. 2 where the error bars refer to statistical errors only. Table I lists the Q-values, the excitation energies and the cross-sections for the levels observed.

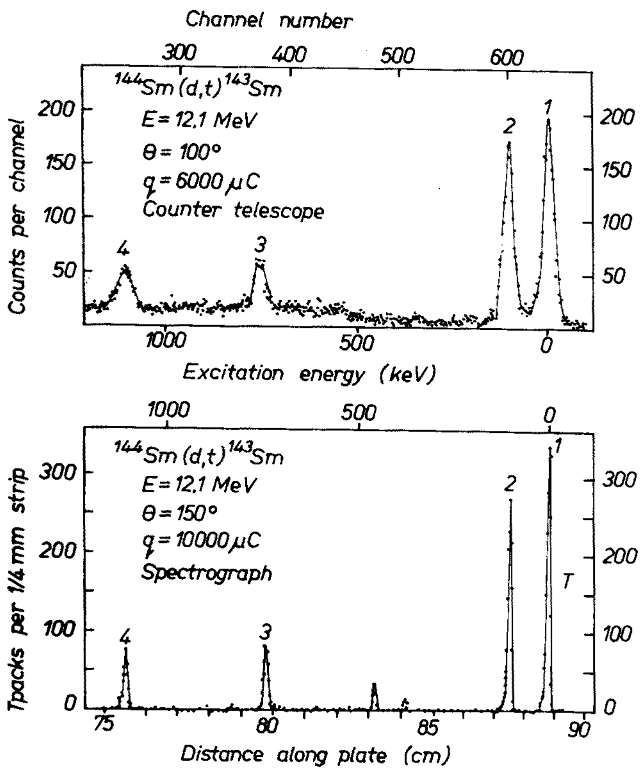

Fig. 1. Triton spectra from the ^{144}Sm(d, t) ^{143}Sm reaction at $E = 12.1$ MeV obtained with the counter and the magnetic spectrograph (triton groups are labelled as *1*, *2*, *3* and *4*)

The angular distributions for the ground state and the 108 keV state are somewhat different, but without pronounced structure. The $l = 2$ ground state transition shows a minimum in the angular distribution around 110°. A similar minimum is found in the distribution for the 108 keV level, but at a slightly smaller angle. This difference between the distributions corresponds qualitatively to the difference between the calculated DWBA distributions for $l = 2$ and $l = 0$ and we therefore make the shell model assignment $s_{1/2}$ for the 108 keV level. This assignment is also in agreement with the large cross-section for this level and with the observation of the $s_{1/2}$ levels at low excitation energies in the other $N = 81$ nuclei [9].

For the levels at 755 keV and 1104 keV we only have the cross-sections at 90°, 125° and 150°. For the 755 keV level the cross-sections follow the expected $l = 5$ dependence

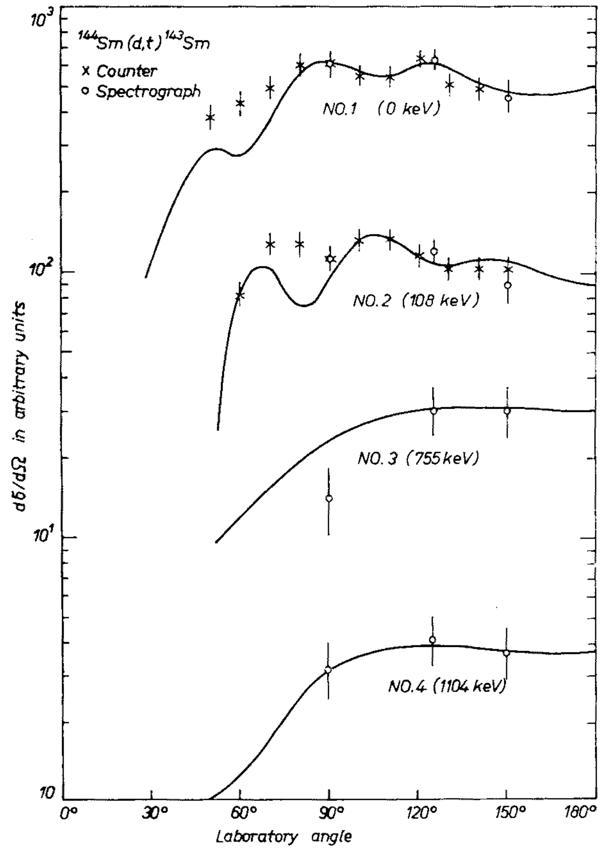

Fig. 2. Angular distributions for triton groups from the ^{144}Sm(d, t) ^{143}Sm reaction. The solid line ahows the result of a **DWBA** calculation

TABLE I

Levels populated in the ^{144}Sm (d, t) ^{143}Sm reaction

No	I, π	Energy keV	Energy previous keV	Q-value MeV	E_d = 12.1 MeV			E_d = 13.1 MeV
					$d\sigma/d\Omega$ 90° μb/sr	$d\sigma/d\Omega$ 125° μb/sr	$d\sigma/d\Omega$ 150° μb/sr	$d\sigma/d\Omega$ 150° μb/sr
1	3/2+	0	0	—4.262	125.5	131.3	92.5	97.0
2	1/2+	108	—	—4.369	95.0	102.1	74.0	81.3
3	11/2—	755	754.4+0.7[4]	—5.014	10.6	22.5	22.6	32.7
4	(5/2+)	1104	—	—5.365	16.2	21.1	18.5	39.7

whereas a somewhat lower l is indicated for the group at 1104 keV. The points are in agreement with the calculated $l = 2$ distribution which would lead to a $d_{5/2}$ assignment, but this evidence is, of course, meagre.

The DWBA curves shown in Fig. 2 were obtained by means of the DWBA code Julie with a set of empirical parameters which were obtained from angular distributions for the ^{160}Gd(d, t)^{159}Gd reaction [8]. It was possible to get somewhat improved fits to the observed triton distributions by slight changes in the triton parameters but the original parameters were preferred in order to avoid ambiguities in the comparison of spectroscopic factors.

It is special interest to calculate the spectroscopic factors for the low lying states in ^{143}Sm as they can be expected to correspond to fairly pure single particle neutron hole states. If this is the case the spectroscopic factors obtianed can serve as a check of the distorted wave procedure widely used in analyses of other (d, t) reactions.

The spectroscopic factors S_l were obtained from the experimental differential cross--sections by means of the equation

$$\frac{d\sigma}{d\Omega} = 3.0 \times S_l \sigma_l(\theta)$$

where $\sigma_l(\theta)$ is the angular function obtained from the DWBA calculation. The normalization factor 3.0 is the same as that used for the (d, t) reactions in deformed nuclei [10].

The extracted spectroscopic factors divided by $(2j+1)$ are listed in Table II. They are all close to 0.6 and are not very sensitive to the details of the calculations. If the ^{143}Sm single neutron hole states are pure, the spectroscopic factors given in Table II should be

TABLE II

Spectroscopic factors

Level keV	I, π	$S_l/(2j+1)$ 90°, 12 MeV	$S_l/(2j+1)$ 150°, 12 MeV	$S_l/(2j+1)$ 150°, 13 MeV	$S_l/(2j+1)$ Average
0	3/2+	0.81	0.63	0.47	0.64
108	1/2+	0.69	0.73	0.62	0.68
755	11/2−	0.46	0.90	0.51	0.62
1104	(5/2+)	0.63	0.54	0.39	0.52

close to unity. Whether the deviation between this expectation and the experimental results reflects a defect in the DWBA treatment or a splitting of the single particle strength in ^{143}Sm is difficult to decide. The spectra do not give evidence for additional $s_{1/2}$, $d_{3/2}$ or $h_{11/2}$ components within the 2 MeV of excitation which could be recorded in the present experiments, but the (d, t) cross-section will be very small at the very negative Q-values and weak groups at higher excitation energy could easy escape detection.

It should be noted that the normalization factor N and the optical potentials used in the DWBA treatment for the deformed nuclei [8] of Gd give spectroscopic factors in close agreement with the theoretical values. For the components $d_{3/2}$, $s_{1/2}$ and $h_{11/2}$ one finds for four deformed Gd nuclei average spectroscopic factors [10] which are 0.83, 0.99 and 0.90, respectively.

These numbers can be directly compared to the spectroscopic factors 0.64, 0.68 and 0.62 for the same components in ^{143}Sm which are roughly 30% lower than those for the deformed nuclei.

Our results are in agreement with the recent assignment given by Chaumeaux *et al.* [11].

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