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STUDY OF THE ^{86}Sr(τ, α)^{85}Sr REACTION

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Abstract: The structure of the ^{85}Sr nucleus has been investigated by measuring the angular distributions of α-particles from the ^{86}Sr(τ, α)^{85}Sr reaction at a bombarding energy of 17.5 MeV, with a 90 cm split-pole magnetic spectrograph. Angular distributions from 6° to 80° have been obtained for the ground state and levels with excitation energies of 0.23, 0,74, 0.90, 1.14, 1.23, 1.62, 1.96 and 2.14 MeV. A DWBA analysis provides l-values and spectroscopic factors for all but one of these levels.

E | NUCLEAR REACTIONS ^{86}Sr(τ, α), $E = 17.5$ MeV, measured $\sigma(E_\alpha, \theta)$. ^{85}Sr deduced levels, l, π, spectroscopic factors. Enriched target.

1. Introduction

Nuclei near the closed neutron shell at $N = 50$ have been the object of many recent experimental and theoretical studies [1-6]. The shell-model calculations on ^{88}Sr and ^{89}Sr by Hughes [3]) gave reasonable agreement with the experimentally observed excitation energies. In the calculations, either ^{88}Sr or ^{90}Zr is usually assumed to be an inert core. Initial comparisons with insufficient experimental data seemed to indicate that this assumption was justified [7-10]). However, a recent experiment has shown significant disagreement with shell-model calculations for ^{91}Y in which ^{88}Sr was considered to be an inert core [11]). Obviously, more experimental information is necessary for a useful comparison with shell-model calculations.

To provide more information about the low-lying levels of ^{85}Sr, a study of the ^{86}Sr(τ, α)^{85}Sr reaction has been carried out. This paper reports excitation energies, and l_n values and spectroscopic factors deduced from a distorted-wave analysis of angular distribution measurements.

2. Experimental method

The measurements were carried out with the Utrecht 6 MV tandem accelerator, with a doubly ionized ^{3}He beam of 17.5 MeV. A detailed description of the experi-

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mental arrangement is given in ref. [13]). The incident beam of about 0.5 μA had 1 mm diameter on the target.

Some preliminary measurements were performed in a scattering chamber, with four surface-barrier detectors with which angular distributions were measured from 25° to 60° in steps of 5°. The energy calibration of the spectra has been performed by measuring some spectra of the ^{88}Sr(τ, α)^{87}Sr reaction, previously investigated by other authors [1]). On the basis of these measurements, the location of the position-sensitive detectors in the focal plane of the split-pole spectrograph was calculated in such a way that the angular distributions between 6° and 80° for all levels up to $E_x = 2.2$ MeV could be measured with only one setting of the magnetic field at each angle. The aperture of the magnetic spectrograph defined a solid angle of 1.2 msr.

The target, consisting of SrO (enriched to 98.6 % in ^{86}Sr), was obtained by evaporation onto a 20 μg/cm^2 carbon foil. Its thickness, evaluated by measuring the energy loss of α-particles emitted by a ^{241}Am–^{244}Cm source, was 200 μg/cm^2. The total resolution, mainly determined by the target thickness, was about 35 keV.

In order to determine the excitation energies of levels in ^{85}Sr with the accuracy characteristic for the magnetic spectrograph, two spectra of the ^{88}Sr(τ, α)^{87}Sr reaction were measured with the same magnetic field as in the case of the ^{86}Sr(τ, α)^{85}Sr reaction. In this way, at least one peak corresponding to a known level of ^{87}Sr was obtained in each of the three position-sensitive detectors used in the measurements. The excitation energies of the ^{85}Sr levels corresponding to peaks in the vicinity of these known peaks could thus be determined with an accuracy of about 10 keV (see table 2).

The intensity was normalized on the basis of the indications of a Faraday cup and of a Si monitor detector fixed at 90°. The statistical error in the measured cross sections is generally less than 10 %, except for the weakly excited levels at large angles ($\theta > 50°$) where it sometimes reaches 20 %.

A number of additional measurements was performed in order to determine the absolute cross sections. The elastic scattering of 4 MeV deuterons was measured in the scattering chamber at four angles between 25° and 40°, with the same target and geometry. Similarly, the elastic scattering of 4 MeV ^{3}He particles was measured with the magnetic spectrograph at five angles between 25° and 45°. In both cases, only the Rutherford scattering is expected to be significant, which was confirmed by the measurements with good accuracy. Furthermore, the elastic scattering of 17.5 MeV ^{3}He particles was measured simultaneously with the (τ, α) reaction. A comparison with optical-model predictions, with the parameter sets used for ^{86}Kr [ref. [1])] and ^{88}Sr [ref. [2])], has confirmed the normalization obtained from the 4 MeV data. The overall uncertainty in the cross section is between 10 and 15 %, except for the 1.96 MeV level for which the statistical errors were large.

Fig. 1 shows the spectrum of α-particles emitted at 45°. The nine peaks, of which the energies were calculated as mentioned above, lead to the ^{85}Sr level scheme shown in fig. 2. The level scheme from ref. [12]) is given for comparison. In general the two sets of data are in good agreement. The 0.77 and 1.87 MeV levels from ref. [12]) are apparently very weakly excited in the (τ, α) reaction. Three new levels, at 900 ± 15, 1230 ± 15 and 1960 ± 10 keV are excited in the present experiment.

When the present paper was in a final stage of preparation, we have learnt about a study of the ^{85}Sr nucleus by means of the ^{84}Sr(d, p) and ^{86}Sr(d, t) reactions [19]).

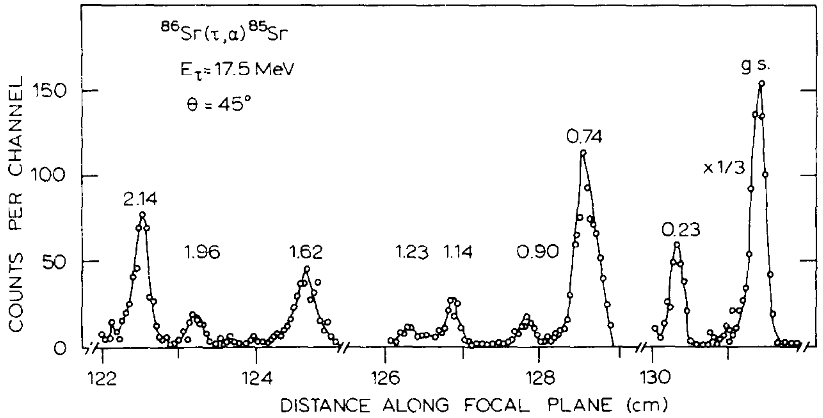

Fig. 1. A typical spectrum taken with position sensitive detectors in the split-pole magnetic spectrograph at $\theta_{\text{lab}} = 45°$.

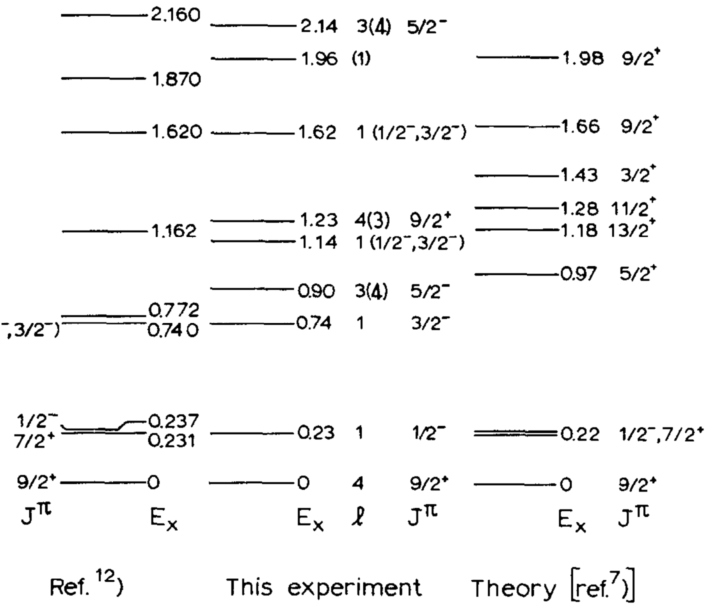

Fig. 2. Level scheme for ^{85}Sr from the present investigation. The J^π values for the 0.74, 0.90, 1.23 and 2.14 MeV levels are given on the basis of shell-model considerations. For comparison, the level scheme from ref. [12]) and that calculated in ref. [7]) are also shown.

In general, one finds good agreement with the results of the present work. The excitation energies from ref. [19]) are slightly different from those determined in the (τ, α) reaction. The $E_x = 1.23$ MeV state is not listed in ref. [19]).

3. Analysis

The measured angular distributions are shown in fig. 3. The theoretical curves were calculated with the DWBA code DWUCK. Two sets of optical-model parameters, as shown in table 1, were used. Both sets were successfully used in analyses of (τ, α) reactions on nuclei in the same mass region [1,2]). The curves corresponding to the two sets show unimportant differences in shape. The Q-value [14]) of the $^{86}\mathrm{Sr}(\tau, \alpha)^{85}\mathrm{Sr}$ reaction, $Q = 9.05$ MeV, implies a mismatch between the angular momentum in the ^{3}He and α-particle channels leading to low-lying states [1,2,15]), especially for $l = 1$ transfer. This is a possible explanation of the fact that some theoretical $l = 1$ curves

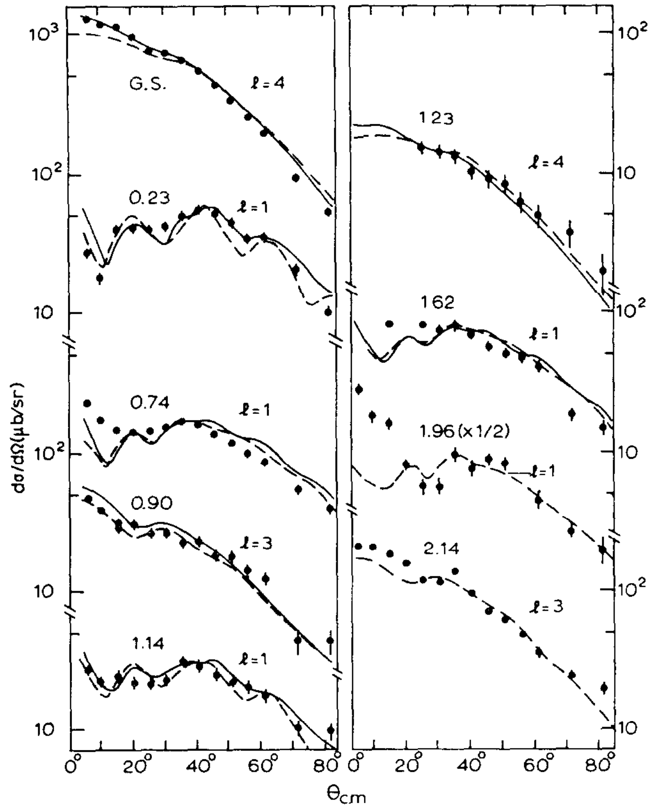

Fig. 3. Experimental differential cross sections. The solid lines are the results of DWBA calculations with optical model parameter set 1 from table 1, the broken lines are calculated with parameter set 2. The values $J = \frac{1}{2}$ and $\frac{3}{2}$ are taken in these calculations for the 1.14 and 1.62 MeV states, respectively.

Table 1

Optical potential parameters used in the DWBA analysis

		V (MeV)	r (fm)	a (fm)	W_{vol} (MeV)	r_w (fm)	a_w (fm)	$V_{\text{s.o.}}$ (MeV)	r_0 (fm)	$\lambda_{\text{s.o.}}$
Set 1	τ	170.0	1.14	0.75	20.0	1.60	0.80	8.0	1.40	
	α	207.0	1.30	0.65	28.0	1.30	0.52	0	1.40	
	n		1.20	0.65						25
Set 2	τ	142.4	1.362	0.65	12.67	1.755	0.781	8.05	1.40	
	α	183.7	1.40	0.56	26.0	1.48	0.56	0	1.40	
	n		1.20	0.65						25

fall below the measured points at forward angles. The angular distribution of the 1.96 MeV level is only partially reproduced by an $l = 1$ curve at angles larger than 20°.

The DWBA analysis has provided l-values for all levels, except for the 1.96 MeV level, for which some uncertainty remains. Though the angular distributions for $l = 3$ and 4 are rather structureless, their behaviour at forward angles is different (fig. 4). The different slopes for $l = 3$ and $l = 4$ reported in ref. ^{2}) were not observed in the present work. The $l = 1$ angular distributions have a characteristic oscillatory shape, very different from that for $l = 0$ and 2 (see fig. 4).

The spins listed in the middle part of fig. 2 were used in the DWBA calculations (they are equal to the spin of the shell-model orbital from which the neutron is picked up). The $\frac{9}{2}^+$ and $\frac{1}{2}^-$ values for the ground state and the 0.23 MeV state, respectively, are taken from previous work ^{12,16}). The 0.24 MeV ($\frac{7}{2}^+$) three-hole state ^{12}) is not

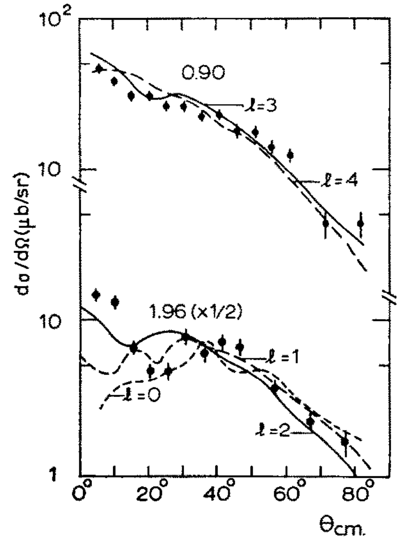

Fig. 4. Comparison between DWBA curves with different l-values.

expected to be strongly excited in the present experiment. The $\frac{3}{2}^-$ value for the 0.74 MeV state is suggested on the basis of shell-model considerations, as well as by the systematics of J^π values in this mass region [1,2]. The $l = 3$ states are supposed to represent the capture of a $1f_{\frac{5}{2}}$ neutron. Though the $J = \frac{7}{2}$ value is also possible, and though the DWBA curves calculated with this value are very similar to those calculated with $J = \frac{5}{2}$, one would expect $\frac{7}{2}^-$ states to appear at much higher excitation energy. It is also difficult to assign a unique spin to the $l = 1$ levels at 1.14 and 1.62 MeV. One sees in fig. 5 that though the DWBA curves corresponding to the two possible spin values ($\frac{1}{2}$ and $\frac{3}{2}$) are slightly different, a unique choice is impossible.

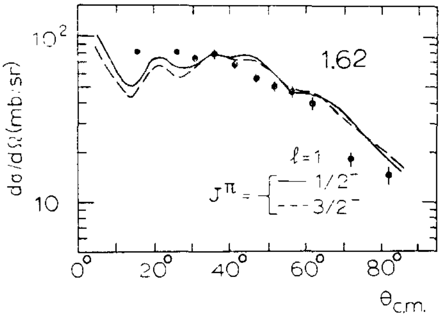

Fig. 5. Comparison between DWBA curves for $l = 1$ transfer to levels with the two possible spin values.

A comparison of the resulting level scheme with the three-nucleon calculations of Talmi and Unna [7]) shows only a limited agreement. Only up to $E_x = 1$ MeV levels are found as predicted by these calculations (though the 0.74 and 0.77 MeV levels are not predicted), whereas at energies larger than 1 MeV a detailed comparison cannot be made. In fact, the first four states could be simply interpreted as hole states in the $1g_{\frac{9}{2}}$, $2p_{\frac{1}{2}}$, $2p_{\frac{3}{2}}$ and $1f_{\frac{5}{2}}$ shells. However, a certain fraction of the strength of all these orbitals is found in transitions to states which lie at energies higher than 1 MeV. This fragmentation could be understood, for example, as resulting from a coupling of particle states to the vibrational states of a doubly even core. Calculations based on such a model were performed for the ^{87}Sr nucleus [21]). Unfortunately, the theoretical predictions and the experimental results [19]) disagree at higher excitation energy, both in the energy position and number of states.

A normalization constant equal to 25 has been used for the DWBA cross section (calculated in the zero-range approximation), in agreement with values obtained in other experimental [1,2]) and theoretical [18]) work. It should be mentioned that the normalization value for the (τ, α) reaction has been subject to many discussions and controversy, which are not yet concluded [18,20]).

The spectroscopic factors deduced from this analysis are given in table 2. The values calculated with the two sets of optical model parameters mostly differ by less

TABLE 2

Summary of the informaion obtained from the ^{86}Sr(τ, α)^{85}Sr reaction

E_x (keV)	l	J^{π} a)	S (set 1)	S (set 2)
0	4	$\frac{9}{2}^+$	7.40	8.40
234± 8	1	$\frac{1}{2}^-$	1.66	1.27
740±10	1	$\frac{3}{2}^-$	3.18	2.72
900±15	3(4)	$\frac{5}{2}^-$	0.40	0.40
1140±10	1	$\frac{1}{2}^-$	0.48	0.40
		$\frac{3}{2}^-$	0.44	0.39
1230±15	4(3)	$\frac{9}{2}^+$	0.07	0.09
1620±10	1	$\frac{1}{2}^-$	0.78	0.70
		$\frac{3}{2}^-$	0.66	0.61
1960±10	(1)			(0.14)
2141± 9	3(4)	$\frac{5}{2}^-$		0.80

a) The J^{π} values for the 0.74, 0.90, 1.24 and 2.14 MeV levels are given on the basis of shell-model considerations.

than 20 %. It is found that the sum of the spectroscopic factors for the $l = 4$ transitions (assumed to represent states excited by $1g_{\frac{9}{2}}$ neutron pick-up) is about 8. This value is in good agreement with the sum rule of French and Macfarlane 17).

An attempt to assign spin values for the $l = 1$ levels at 1.14 and 1.62 MeV is possible on the basis of the sum-rule limits. So, assuming $J = \frac{1}{2}$ and $\frac{3}{2}$ for the $E_x = 1.14$ and $E_x = 1.62$ MeV levels, respectively, the sum of the spectroscopic factors for the $2p_{\frac{1}{2}}$ states is 2.14 (calculated with set 1), or 1.67 (set 2), and that for the $2p_{\frac{3}{2}}$ states is 3.84 (set 1), or 3.33 (set 2). This is in reasonable agreement with the theoretical values 2 and 4, the maximum occupation numbers of $2p_{\frac{1}{2}}$ and $2p_{\frac{3}{2}}$ neutrons, respectively (it is to be noted that the 1.96 MeV state, with $l = (1)$, contributes at most 0.14 to the sum).

However, not too much significance should be attached to such an agreement, in view of the uncertainty related to the normalization of the DWBA calculation. Possible effects which could change the values predicted by the sum rule (like the pairing force) are not excluded. Nevertheless, the agreement between the spectroscopic factors reported herein, and those obtained from the (d, t) reaction 19) is noticeable.

Only a small amount of the strength corresponding to neutron pick-up from the $1f_{\frac{5}{2}}$ shell is observed.

4. Conclusions

The (τ, α) reaction proved useful in obtaining information on the structure of ^{85}Sr. The DWBA analysis resulted in a unique determination of several $l = 1$ values while $l = 3$ and 4 were difficult to distinguish. In the calculation of spectroscopic factors the indicated choice between $l = 3$ or 4 was made on a shell-model basis. The dependence of the cross sections on the total angular momentum transfer is practically absent, which makes unique spin assignments impossible. The spectroscopic factors deduced in this analysis obey the limits imposed by the sum rules.

Now, as more experimental information for the nuclei around $N = 50$ exists, a more extended shell-model calculation in this region seems to be useful.

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