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ABSTRACT. -

The reactions $^{32}S(^{3}He, d)^{33}Cl$ and $^{33}S(^{3}He, \alpha)^{32}S$ have been studied at $E(^{3}He) = 10.4$ MeV. The stripping spectroscopic factors are very close to the shell model calculations. The pick-up spectroscopic factors are higher than the MSDI predictions, due to the failure of DWBA in treating the high Q-value $(^{3}He, \alpha)$ reactions.

Spectroscopic information on energy levels of nuclei in the s-d shell, obtained by several authors in the last years, showed good agreement with recent calculations based on a many-particles shell-model[1]. In this paper we present experimental results obtained from the reactions $^{32}S(^{3}He, d)^{33}Cl$ and $^{33}S(^{3}He, \alpha)^{32}S$, studied to compare spectroscopic factors of states correlated by stripping and pick-up reactions. Besides, these data can provide further tests to the shell-model wave functions. The angular distributions of outgoing deuterons and alpha particles for low-lying levels in ^{33}Cl and ^{32}S have been analysed and the corresponding spectroscopic factors extracted with the help of DWBA calculations.

The measurements were carried out with the 5.5 MV Van de Graaff accelerator of the Laboratori Nazionali di Legnaro (Padua), at an incident energy of 10.4 MeV. The targets consisted of PbS, enriched to 25.54% in ^{33}S, evaporated onto thin Carbon backings. Spectra from the reaction $^{32}S(^{3}He, d)^{33}Cl$ were obtained over the range of laboratory angles from 15^{o} to 48^{o}. The deuterons from this reaction were observed by means of surface barrier telescopes and pulse multiplica-

tion identification technique. The alpha particles from the reaction ^{33}S (^{3}He,)^{32}S were detected by means of surface barrier detectors, at laboratory angles from 18° to 93°. The overall resolution in energy was about 120 KeV. Absolute cross sections were obtained by normalising to the elastic scattering of 10.4 MeV ^{3}He-particles on Pb, with the assumption that in these conditions only Rutherford scattering is significant.

A typical energy spectrum of the $^{32}S(^{3}He, d)^{33}Cl$ reaction, taken at $\theta_{lab} = 27°$, is shown in Fig. 1. The measured angular distributions for this reaction are displayed in Fig. 2 together with DWBA curves, obtained by means of the DWUCK[2] computer code, in the local, finite range approximation, making use of a (^{3}He, d) normalization of 4.42[3] to extract spectroscopic factors. The optical model parameters for the entrance channel were obtained from the analysis of the elastic scattering of ^{3}He-particles on sulphur. The potential was chosen with the request of being α-like, as it is suitable in the analyses of ($^{3}He, \alpha$) reactions[4]. These parameters are listed in Table I together with the exit channel-parameters, taken from ref. (5). The quality of the fits can be considered quite satisfactory. The use of other sets of parameters[6] gave nearly identical fits. For the 2.686 MeV level in ^{33}Cl theoretical predictions are shown in the two hypotheses $j^{\pi} = 3/2^{+}$, $7/2^{-}$, although the $7/2^{-}$ value seems now to be in a better agreement with the results of other experimental works[6,7].
Our data, taken at a relatively low energy, don't allow a decision between these two assignments. Spectroscopic factors obtained from our work are listed in Table II, compared with those of other authors and with the theoretical values from the MSDI[1] and ICVM[8] models. The agreement is fairly good. Levels in ^{33}Cl above 2.28 MeV in excitation are proton unstable, therefore the corresponding spectroscopic factors had to be determined extrapolating to negative binding energies, as we could use only bound states in DWUCK.

The angular distributions of alpha-groups observed in the $^{33}S(^{3}He, \alpha)^{32}S$ reaction, corresponding to the ground state and to the 2.237 MeV and 3.780 MeV levels, are shown in Fig. 3. An angular distribution from the $^{32}S(^{3}He, \alpha)^{31}S$ reaction (relative to the ground state transition) is also shown. The curves in Fig. 3 were obtained by means of DWBA calculations, only local, zero range, with no lower cut-off, as Stock et al.[4] suggest, making use of the optical model parameters of Table I. The parameters for the alpha-particles were taken from an analysis of the elastic scattering of alpha particles on ^{34}S, studied by Leighton et al.[9] at an incident energy of 18 MeV. As it is apparent from the figure, DWBA calculations reproduce quite well the trend of the experimental points for the transitions to the ground state and to the two excited levels in ^{32}S. On the contrary, for the ground state transition in the $^{32}S(^{3}He, \alpha)^{31}S$ reaction they give a curve with slightly shifted maxima and minima with respect to the experimentally observed ones. The same

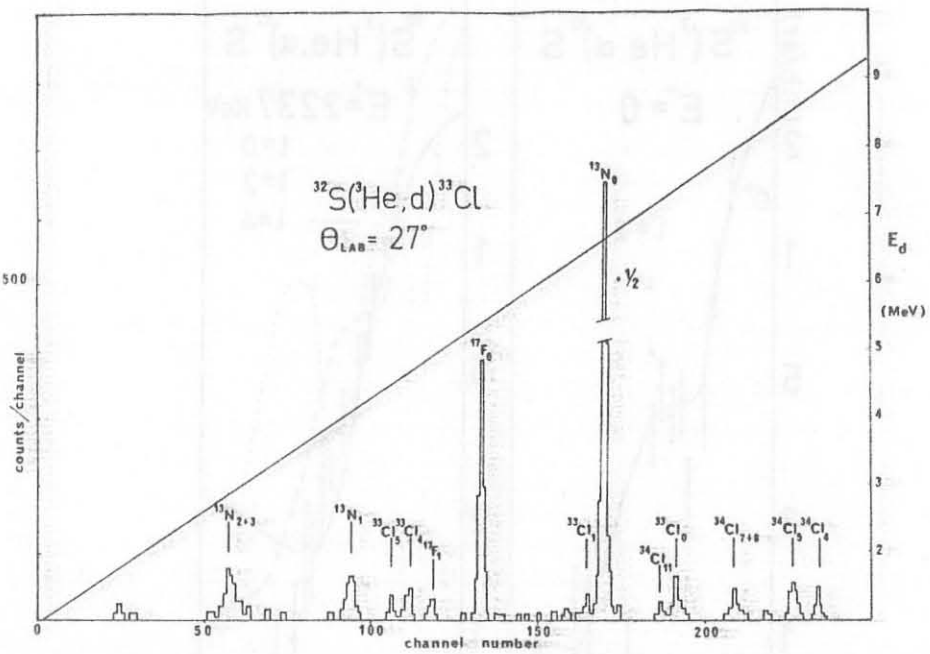

FIG. 1 - Energy spectrum from the $^{32}S(^{3}He, d)^{33}Cl$ reaction.

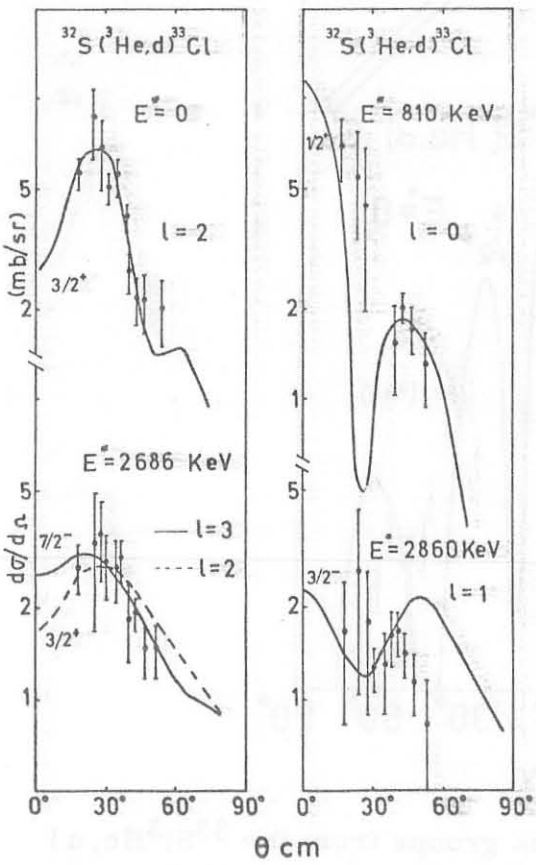

FIG. 2 - Angular distributions of deuteron groups from the $^{32}S(^{3}He, d)^{33}Cl$ reaction; DWBA curves, excitation energies and ℓ-values are also shown. Errors include background subtraction correction.

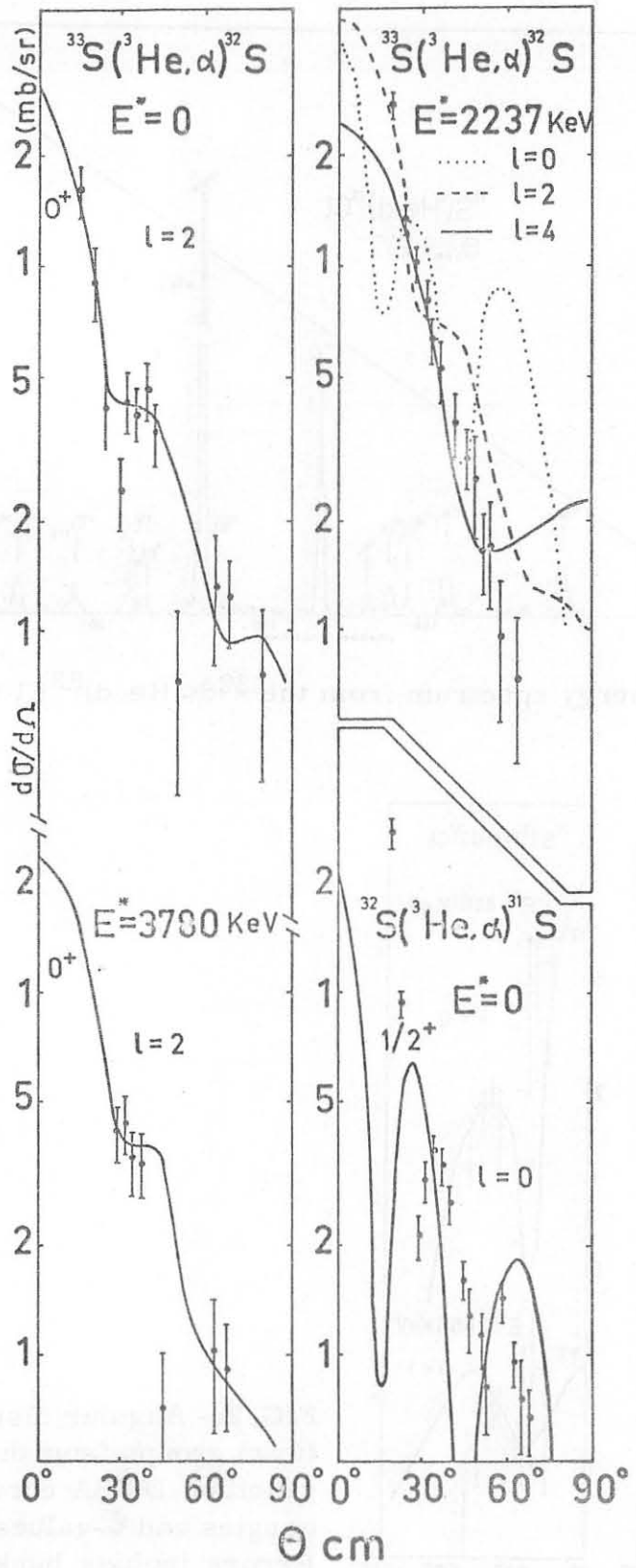

FIG. 3 - Angular distribution of alpha groups from the $^{33}S(^3He,\alpha)^{32}S$ and $^{32}S(^3He,\alpha)^{31}S$ reactions. See also caption of Fig. 2.

Table 1. Optical Model Parameters used for DWBA analyses.

	V_R (MeV)	r_{OR} (fm)	r_{OC} (fm)	a_R (fm)	V_I (MeV)	W_D (MeV)	r_{OI} (fm)	a_I (fm)	V_{SO} (MeV)
^3He a)	137.7	1.42	1.40	0.70	18.7		1.44	0.45	9.2
d b)	63	1.40	1.30	0.70		8	1.40	0.70	
^4He c)	185	1.40	1.40	0.53	14.4		1.48	0.64	

a) Present work

b) ref.5

c) ref.9

Table 2. Spectroscopic factors from the reaction $^{32}S(^3He,d)^{33}Cl$

E_x (MeV)	l_p	j^π	c^2S, experiment 10.4 MeV a)	15.0 MeV b)	29.7 MeV c)	34.5 MeV d)	c^2S, theory MSDI e)	ICVM f)
0.0	2	$\frac{3}{2}^+$	0.54	0.90	0.70	0.63	0.64	0.77
0.810	0	$\frac{1}{2}^+$	0.22	0.29	0.32	0.37	0.27	0.28
2.358	2	$\frac{3}{2}^+$				0.061	0.07	0.04
		$\frac{5}{2}^+$				0.033		
2.686	3	$\frac{7}{2}^-$	0.52	0.73	0.50	0.41		
	(2)	$\left(\frac{3}{2}^+\right)$	(1.13)	(1.30)				
2.860	1	$\frac{3}{2}^-$	0.72	0.55	0.50	0.58		

a) Present work c) ref.7 e) ref.1

b) ref.6 d) ref.7 f) ref.8

Table 3. Spectroscopic factors from the $^{33}S(^3He,^4He)^{32}S$ and $^{32}S(^3He,^4He)^{31}S$ reactions.

	E_x (MeV)	l_n	j_{tr}	J^π	c^2S, experiment 8 MeV a)	10.4 MeV b)	15 MeV c)	33.6 MeV (p,d) d)	c^2S, theory MSDI e)
	0.0	2	$\frac{3}{2}$	0^+		4.00			0.64
	2.237	0	$\frac{1}{2}$	2^+		9.56			0.54
$^{33}S(^3He,^4He)^{32}S$		2	$\frac{3}{2}$			2.75			0
		2	$\frac{5}{2}$			2.66			0
		4	$\frac{7}{2}$			0.43			
	3.780	2	$\frac{3}{2}$	0^+		0.75			0.07
$^{32}S(^3He,^3He)^{31}S$	0.0	0		$\frac{1}{2}^+$	4.40	0.74	0.90	1.04	1.13

a) Ref.1 c) ref.11 e) ref.1

b) present work d) ref.12

characteristic has also been noted by other authors[10, 11].
For what concerns the excited state at 2.237 MeV in ^{32}S, the theoretical curves corresponding to three different ℓ-values are shown in Fig.3. An $\ell = 4$ or 2 assignment seems to be the most probable from our experimental data. There is no essential difference between the theoretical curves in the two hypotheses $j = 2 \pm 1/2$, when $\ell_n = 2$, with the exception of a slightly larger cross section in the case $j = 2 + 1/2$. The spectroscopic factors for the $^{33}S(^3He, \alpha)^{32}S$ and $^{32}S(^3He, \alpha)^{31}S$ reactions were extracted with the normalization $\sigma_{exp}(\theta) = 23\ c^2S\ \sigma_{DW}(\theta)/(2J+1)$ and the results, together with those from other experimental works and with theoretical calculations, are listed in Table III.

Spectroscopic factors of states which may be connected by stripping and pick-up reactions should be identical, independently from the nuclear model adopted. Therefore, under the assumption of charge independence of the nuclear forces, the stripping-factor for the ground state in ^{33}Cl should be equal to the pick-up S-factor for the ^{32}S ground state transition. On the contrary, we find that the pick-up spectroscopic factor is about six times higher than both the corresponding stripping S-factor and the theoretical values from the MSDI and ICVM models. Moreover, also the remaining pick-up S-factor from the $^{33}S(^3He, \alpha)^{32}S$ reaction are larger than the calculated ones. This disagreement can be explained in terms of a failure of DWBA in treating high Q-value $(^3He, \alpha)$ reactions[4] (in this case Q = 11.927 MeV). Note indeed that for the ^{32}S $(^3He, \alpha)^{31}S$ reaction (Q = 5.471 MeV) our result fairly agrees with the theoretical value predicted by Wildenthal et al. [1].

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REFERENCES. -

(1) - B. H. Wildenthal, J. B. Mc. Grory, E. C. Halbert and P. W. M. Glaudemans, Phys. Letters 26B, 692 (1968); 27B, 611 (1968); B. H. Wildenthal, J. B. Mc. Grory, E. C. Halbert and H. D. Graber, Phys. Rev. C4, 1708 (1971.
(2) - P. D. Kunz, University of Colorado (USA).
(3) - R. H. Bassel, Phys. Rev. 149, 791 (1966).
(4) - R. Stock, R. Bock, P. David, H. H. Duhm and T. Tamura, Nuclear Phys. A104, 136 (1967).
(5) - A. Adams and J. M. Calvert, Nuclear Phys. A157, 289 (1970).
(6) - R. A. Morrison, Nuclear Phys. A140, 97 (1970).
(7) - R. L. Kozub and D. H. Youngblood, Phys. Rev. C5, 413 (1972).
(8) - B. Castel, K. W. Stewart and M. Harvey, Nuclear Phys. A162, 273 (1971).
(9) - H. G. Leighton and A. C. Wolff, Nuclear Phys. A151, 71 (1970).
(10) - J. E. Mc. Queen, J. M. Joyce and E. J. Ludwig, Nuclear Phys. A151, 295 (1970).
(11) - C. M. Fou and R. W. Zurmuhle, Phys. Rev. 151, 927 (1966).
(12) - R. L. Kozub, Phys. Rev. 172, 1078 (1968).