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Nuclear Physics **A231** (1974) 411–424; © *North-Holland Publishing Co., Amsterdam*

INVESTIGATION OF THE REACTION ^{35}Cl(τ, α)^{34}Cl AT E_τ = 15 MeV

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Received 11 July 1974

Abstract: The ^{35}Cl(τ, α)^{34}Cl reaction has been used to study the properties of ^{34}Cl levels up to an excitation energy of 5 MeV. Angular distributions of 37 levels were measured with a split-pole magnetic spectrograph, at a bombarding energy of 15 MeV. New levels have been found at 3847, 3964, 4206, 4321 and 4715 keV, all $\pm$10 keV. There is a strongly excited multiplet at E_x = 5.0 MeV with components at 4939$\pm$11, 4958$\pm$11, 4971$\pm$11, 4998$\pm$12 and 5010$\pm$13 keV. A DWBA analysis of the α-particle angular distributions yielded l_n values and spectroscopic factors. New spin and parity assignments were obtained. The T = 1 character of the levels at E_x = 4.21 and 4.72 MeV has been determined. Experimental spectroscopic factors are compared with results from recent many-particle shell-model calculations.

E | NUCLEAR REACTIONS ^{35}Cl(τ, α), ^{35}Cl(τ, τ), E = 15 MeV; measured $\sigma(E_\alpha, \theta)$, $\sigma(\theta)$; ^{34}Cl deduced levels, l_n, J, π, T, S. Enriched target.

1. Introduction

Recent investigations of ^{34}Cl by single-particle transfer reactions were performed by Erskine *et al.* ^{1}) and Vignon *et al.* ^{2}). The first group studied the ^{33}S(τ, d)^{34}Cl proton stripping reaction which, for excitation energies E_x > 3.5 MeV, mainly leads to negative-parity states. The neutron pick-up reaction ^{35}Cl(p, d)^{34}Cl was studied by the latter group.

Two-nucleon transfer reactions, leading to ^{34}Cl, like ^{36}Ar(p, τ)^{34}Cl and ^{36}Ar(d, α)^{34}Cl have been studied by Brunnader *et al.* ^{3}). The latter reaction was also investigated by Horoshko and Shapiro ^{4}), with better resolution.

Spectroscopic information which may be used to locate T = 1 levels in ^{34}Cl, was obtained from the ^{35}Cl(d, τ)^{34}S reaction by Wildenthal and Newman ^{5}) and by Puttaswamy and Yntema ^{6}).

All these investigations, except for the ^{33}S(τ, d)^{34}Cl stripping work, suffer from rather poor resolution. The present investigation was undertaken to obtain high-resolution spectroscopic information about ^{34}Cl levels from the neutron pick-up reaction ^{35}Cl(τ, α)^{34}Cl, especially in the E_x = 3.5–5.0 MeV region, and to test results from recent many-particle shell-model calculations.

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2. The experiment

The measurements were carried out with the Utrecht 6 MV tandem accelerator. The targets used in the present investigation consisted of a layer of about 50 $\mu g/cm^2$ $BaCl_2$, enriched to 99.3 % in ^{35}Cl, evaporated on a thin carbon backing. The α-particles were detected in seven position sensitive detectors, located in the focal plane of a split-pole magnetic spectrograph. Although α-particles and protons have equal energies at any point in the focal plane, there was no difficulty discriminating between them, since the latter were not stopped in the detectors and hence gave smaller energy signals. The position and energy pulses from the detectors were stored in an on-line CDC-1700 computer and subsequently written on magnetic tape [5]). To measure the angular distributions for levels up to $E_x \approx 5$ MeV two different sets of detector positions were necessary to fill the inter-detector gaps.

A typical spectrum, at $\theta = 10°$, is shown in fig. 1. The average resolution (FWHM)

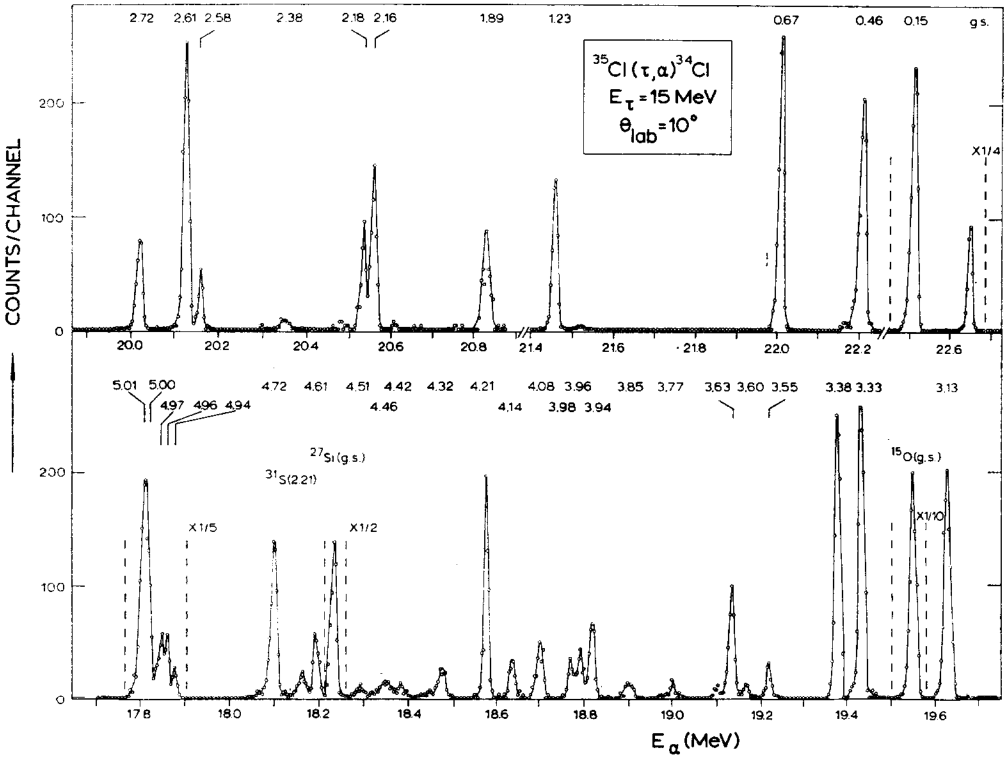

Fig. 1. Spectrum of α-particles from the reaction $^{35}Cl(\tau, \alpha)^{34}Cl$, taken at $\theta = 10°$ with six position sensitive detectors. The spectrum is a composition of two runs for different positions of the detectors. The ^{34}Cl peaks are labeled with their excitation energy in MeV. Contaminant peaks from ^{16}O, ^{28}Si and $^{32}S(\tau, \alpha)$ are indicated as well. The unlabeled small peaks have been only observed at forward angles. They originate mainly from ^{23}Na, which remained in the target material after chemical conversion of NaCl into $BaCl_2$. The average FWHM of the peaks is 15 keV.

is 15 keV. The shift of the position of the α-particle groups on the detectors, due to kinematics, as a function of angle, provided an unambiguous peak indentification. Among the ^{34}Cl peaks, which are labeled by their excitation energies, two rather

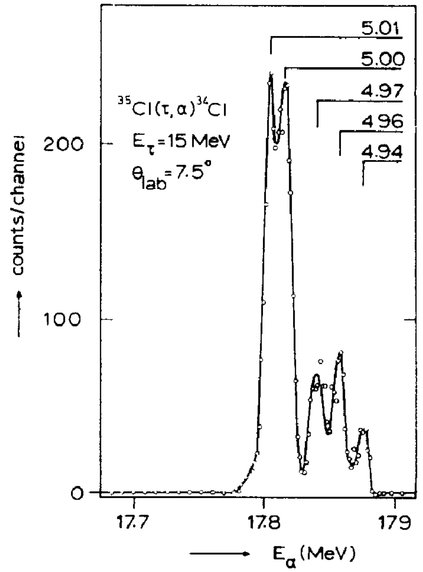

Fig. 2. The multiple group at E_x = 5 MeV in ^{34}Cl with enlarged abscissa scale and increased resolution. The average FWHM of the peaks is 11 keV.

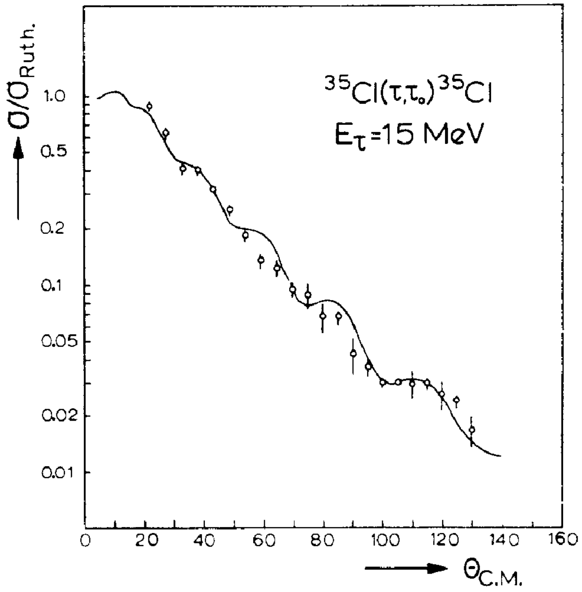

Fig. 3. Optical-model fit to the elastic ^{3}He scattering data with the parameters of table 1.

strong peaks from the contaminants ^{28}Si and ^{16}O appear. The well-known energies of these ground-state groups could be used to determine the excitation energies of some hitherto unknown ^{34}Cl levels in the $E_x = 3.8$–5.1 MeV region. The strongly excited group of levels at $E_x = 5.0$ MeV is shown with better resolution (FWHM $\approx$ 11 keV) in fig. 2.

To obtain the optical model ^{3}He parameters, to be used in the DWBA analysis of the α-particle angular distributions, an elastic-scattering experiment of 15 MeV ^{3}He particles on ^{35}Cl was carried out (fig. 3).

Absolute cross sections were determined by measuring the Rutherford scattering of 5 and 10 MeV ^{3}He particles from ^{35}Cl and ^{137}Ba at $\theta = 25°$, 30° and 35°, with the same target and identical geometry. The results of these measurements were consistent within a few percent.

3. Analysis

An optical-model search program (Perey) was used to extract from the experimental ^{35}Cl(τ, τ_0) data the optical-model ^{3}He parameters. Several α-particle parameter sets from the literature, which fit the criterion that the α-particle potential should be approximately equal to the sum of the ^{3}He and neutron potentials, were tried in the DWBA calculations. Volume absorption potentials were used throughout. In accordance with the advice of Stock *et al.* [9]), only local zero-range calculations without interior cut-off were carried out. In the analysis of the angular distributions of the ^{35}Cl(τ, α)^{34}Cl reaction one encounters several difficulties.

(i) Due to the angular momentum mismatch, the reliability of the DWBA curves is doubtful for low-lying levels [9]).

(ii) Because the spin of the target nucleus is $J = \frac{3}{2}$ several l_n values, differing by two units, may contribute to the angular distributions.

A least-squares fitting program was used to compare the experimental angular distributions (fig. 4) with the DWBA curves for $l_n = 0$, 1, 2 and 3 and for the incoherent sum of l_n and l_n+2 curves.

The program searches for the minimum value of the quantity

$$Q^2(\alpha) = \left[\sum_{i,j} ((e_i - \alpha_j t_{ij})/\delta e_i)^2\right] \Big/ \left[i_{\max} - j_{\max}\right],$$

where i runs from 1 up to the maximum number of angles at which the cross section has been measured ($= i_{\max}$), j numbers the l_n which are taken into account, $(e_i \pm \delta e_i)$ stands for the experimental cross section and t_{ij} for the calculated DWBA cross section at angle i; the α_j are constants proportional to the spectroscopic factors.

Naturally the Q^2 values depend on the statistics obtained in the experiment, and on the quality of the fit of the theoretical curves.

As a matter of fact the DWBA curves, in principle, do not exactly describe the experimental angular distributions and thus Q^2 will not obey a χ^2 distribution. This also means that the expectation value of Q^2, in this analysis, will be substantially larger than 1. Some typical Q^2 values are: for most excited states with $l_n = 2$ character one finds $Q^2 = 3$–8, but for the angular distribution of $E_x = 0.15$ MeV, which has very good statistics, $Q^2 = 29$. Angular distributions with a dominant $l_n = 2$ structure and a relatively small $l_n = 0$ admixture (e.g. at $E_x = 0.46$ and 0.67 MeV) have on the average $Q^2 \approx 10$. Pure $l_n = 0$ angular distributions (and those with a small $l_n = 2$ component) show $Q^2 \approx 25$.

TABLE 1

Potential parameters used in the DWBA calculations

	V (MeV)	r (fm)	a (fm)	W_{vol} (MeV)	r_W (fm)	a_W (fm)	$V_{\text{s.o.}}$ (MeV)	r_0 (fm)	$\lambda_{\text{s.o.}}$
τ	133.5	1.34	0.70	26.7	1.47	0.88	10.0	1.40	
α	185.0	1.40	0.53	14.4	1.48	0.64		1.40	
n		1.25	0.65						25

In some cases a constant background, added to the calculated cross section, considerably improved the fit. This compound-nucleus background has a strength of about 10 μb/sr, equal to the average cross section for the levels without pick-up pattern.

A mixture of two DWBA curves, of course, always gives a better fit than only one. But such a mixture was considered to be realistic only if both components were found to be stronger than five times the average compound nucleus contribution in the small-angle region ($\leqq 30°$).

Although for the reasons mentioned above, a Q^2 test is not necessarily very reliable, the l_n (or sum of l_n values) which gave the lowest Q^2 was taken to be the proper l_n (or combination of l_n values) for that particular angular distribution. Spectroscopic factors, S_n, were obtained from the relation $\sigma_{\text{exp}} = NC^2S_n\sigma_{\text{DWBA}}$. The normalization factor N has the value 23±5 [ref. [9]] and C is a Clebsch-Gordan coefficient ($C^2(T = 0) = 1$, $C^2(T = 1) = \frac{1}{3}$).

Systematic errors of about 30 % in the spectroscopic factors may arise from the DWBA approximation. Relative errors are of the order of 10 % in the case of single l_n levels where compound nucleus contributions do not influence the measured cross section. For weak levels where the influence of compound nucleus contributions cannot be neglected this error is larger.

4. Results and discussion

4.1. RESULTS

The α-particle angular distributions for transitions to ^{34}Cl levels are shown in fig. 4. Angular distributions which only show a compound nucleus contribution have been omitted from this figure.

The 1923±2 keV level reported by Erskine *et al.* [1]) has not been observed in the

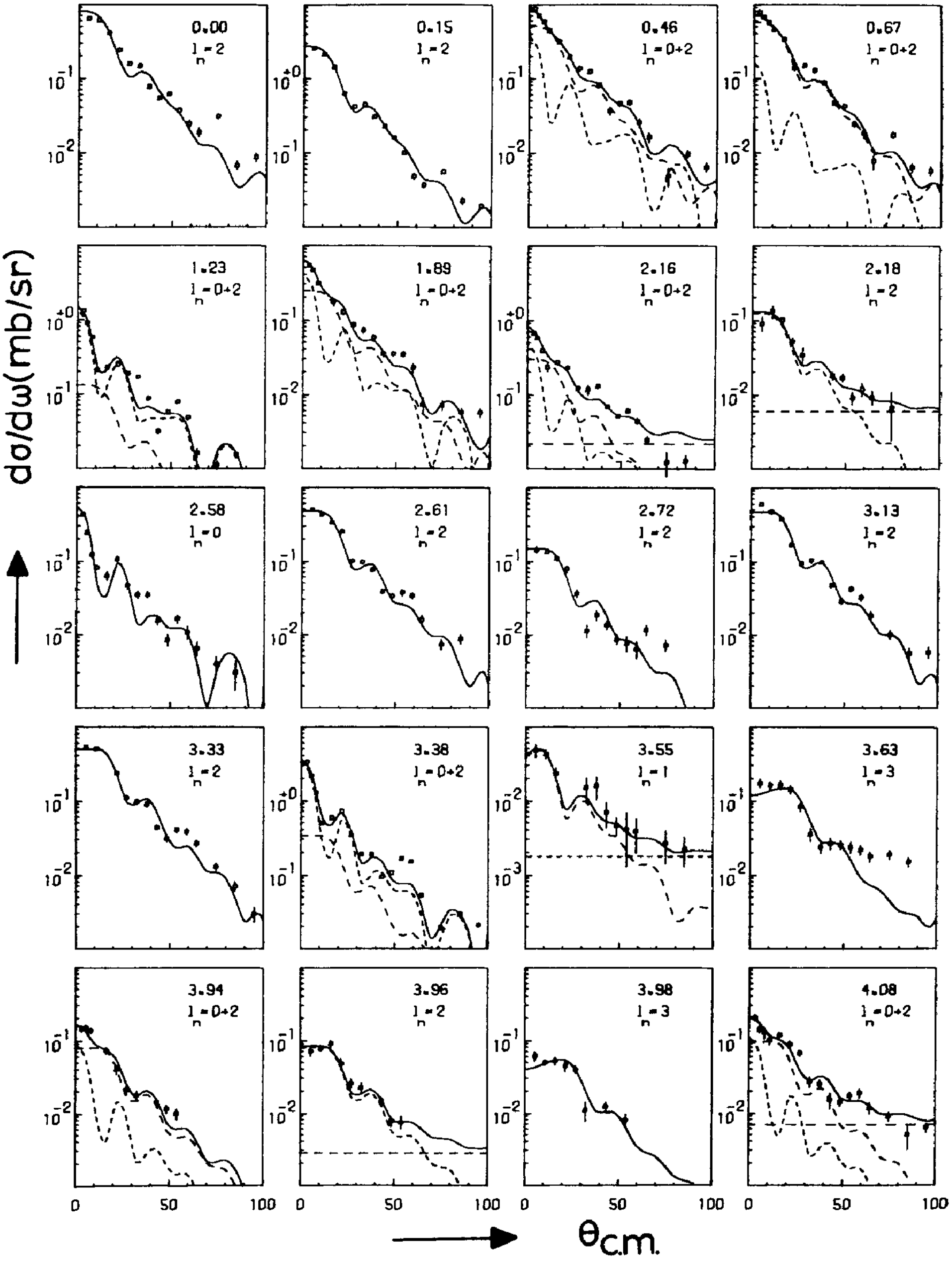
0.00 l_n=2
0.15 l_n=2
0.46 l_n=0+2
0.67 l_n=0+2
1.23 l_n=0+2
1.89 l_n=0+2
2.16 l_n=0+2
2.18 l_n=2
2.58 l_n=0
2.61 l_n=2
2.72 l_n=2
3.13 l_n=2
3.33 l_n=2
3.38 l_n=0+2
3.55 l_n=1
3.63 l_n=3
3.94 l_n=0+2
3.96 l_n=2
3.98 l_n=3
4.08 l_n=0+2
dσ/dω(mb/sr)
θc.m.
10^+0
10^-1
10^-2
10^-3
0
50
100

Fig. 4a.

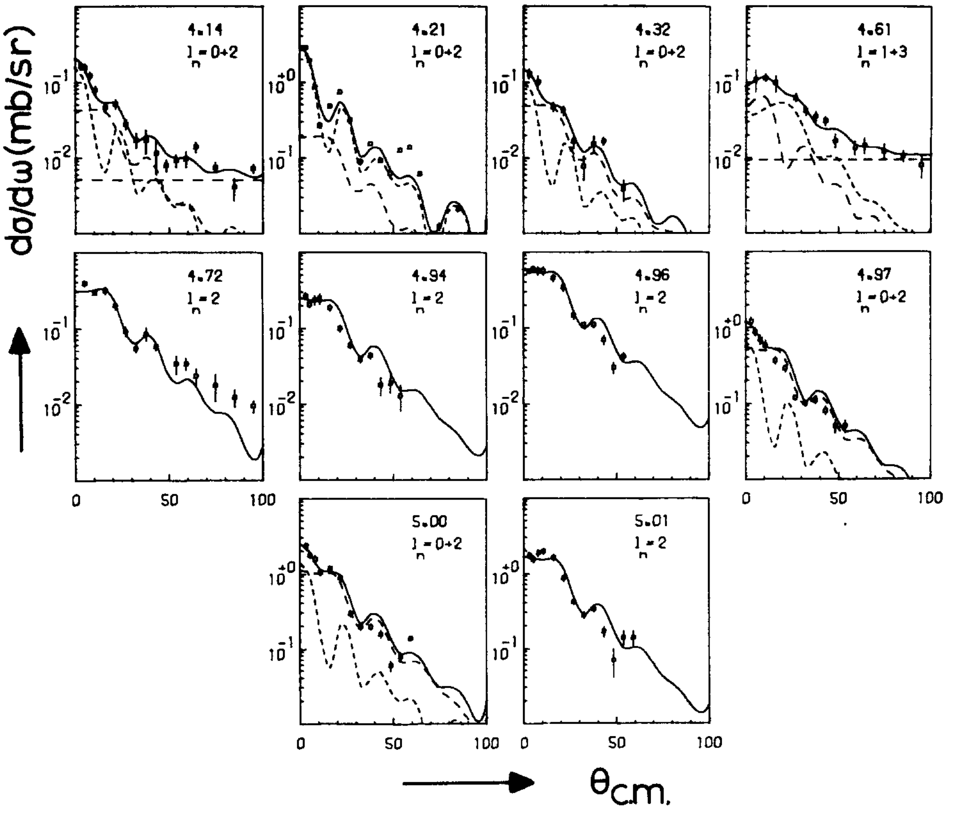

Fig. 4b.

Fig. 4. Experimental differential cross sections. Dotted lines indicate the DWBA result for one component of the final theoretical angular distribution, which is represented by a full line. Horizontal lines indicate the estimated background from compound nucleus formation.

^{35}Cl(τ, α)^{34}Cl reaction. Also the 4.64 MeV level has not been seen in the present experiment; the peak at the corresponding position in the spectrum (fig. 1), visible at $\theta = 5°$, 10° and 15°, is due to an α-particle group from the ^{32}S(τ, α)^{31}S reaction.

The results from the analysis generally were in agreement with the known parity of the levels. However, for the ground state and the level at 0.67 MeV excitation energy a combination of odd l_n values gave a lower Q^2 than the even l_n values, although these levels are known to have positive parity [17]). This is ascribed to the mismatch mentioned above. Therefore, in spite of the result of the fitting program, $l_n = 2$ was accepted for the ground state and $l_n = 0+2$ for the 0.67 MeV level.

There remained a few discrepancies with respect to the parity of some levels. From the ^{33}S(τ, d)^{34}Cl reaction [1]), odd parity was deduced for the level at 2720.7 ± 2.5 keV, whereas in the present investigation a level found at 2718 ± 10 keV shows an angular distribution with $l_n = 2$ character (fig. 2). The possibility of a close doublet consisting

TABLE 2

Spectroscopic data from the ^{35}Cl(τ, α)^{34}Cl reaction

E_x d) (keV)	J^π; T d)	C^2S_n										
		Present exp. a)		FPSDI b)			MSDI b)			11.0h+ASPE c)		
		$l_n = 0$	$l_n = 2$	$s_{\frac{1}{2}}$	$d_{\frac{3}{2}}$	$d_{\frac{5}{2}}$	$s_{\frac{1}{2}}$	$d_{\frac{3}{2}}$	$d_{\frac{5}{2}}$	$s_{\frac{1}{2}}$	$d_{\frac{3}{2}}$	$d_{\frac{5}{2}}$
g.s.	0^+; 1		0.44		0.31			0.27			0.21	
146.36 ± 0.03	3^+		1.5		1.1			1.1			1.0	0.04
461.00 ± 0.04	1^+	0.09	0.26	0.18	0.13	0.02	0.01	0.46			0.02	0.06
665.55 ± 0.05	1^+	0.03	0.31	0.01	0.31	0.01	0.24	0.01	0.01	0.16		0.01
1230.24 ± 0.07	2^+	0.23	0.07	0.18		0.09	0.30		0.06	0.13	0.01	0.10
1887.5 ± 0.5	2^+	0.06	0.14	0.02	0.11	0.03	0.03	0.07	0.02			
2158.3 ± 0.3	2^+; 1	0.10	0.18	0.05	0.11		0.11	0.04		0.05	0.01	0.06
2180.7 ± 0.4	$(2, 3)^+$		0.07									
2376.3 ± 0.4	4^+ f)											
2580.6 ± 1.3	1^+	0.06		0.04	0.01	0.05						
2611.2 ± 1.3	$(1\text{–}4)^+$		*0.23*			0.42			0.53			
2718 ± 10 e)	$(1\text{–}4)^+$ e)		0.07									
2721.7 ± 0.3	2^-											
3128 ± 2	1^+		0.31									
3333 ± 2	$(1\text{–}3)^+$		0.33									
3383 ± 2	2^+; 1	0.27	0.23	0.25	0.09	0.02	0.23	0.09	0.04	0.18	0.01	0.1
3545.2 ± 0.5	3^- g)											
3600.5 ± 0.7	$4^{(-)}$ f)											
3632.5 ± 1.4	5^- g)											
3771.0 ± 0.7	1^- f)											
3847 ± 10 e, f)												
3937 ± 10 e)	$(1, 2)^+$ e)	0.003	0.07									

3964	±10 [e])	0^+; 1		0.06		0.01			0.05		0.08
3982.1	± 0.3	3^-	[g])								
4075	±10	$(1, 2)^+$ [c, h])	0.007	0.08							
4075.4	± 0.9	4^-									
4136.6	± 1.2	$(1, 2)^+$ [c, h])	0.011	0.04							
4206	±10 [e])	$(1)^+$; (1) [e])	0.20	0.05	0.17	0.04	0.01	0.20	0.04	0.01	
4321	±10 [e])	$(1, 2)^+$ [e])	0.007	0.04							
4352.7	± 0.9	1^-									
4416	± 2	$(1–3)^-$ [f])									
4461	± 3	$(2, 3)^-$ [f])									
4514.5	± 0.7	$(2)^-$ [f])									
4608	± 2	$(0–3)^-$ [h])	[g])								
4639	± 2	$(3)^-$ [h])									
4715	±10 [e])	$(4)^+$; (1) [e])		*0.20*			0.05			0.25	
4939	±11 [e])	$(0–4)^+$ [e])		*0.13*							
4958	±11 [e])	$(0–4)^+$ [e])		*0.30*							
4971	±11 [e])	$(1, 2)^+$ [e])	0.04	*0.28*							
4998	±12 [e])	$(1, 2)^+$ [e])	0.08	*0.56*							
5010	±13 [e])	$(0–4)^+$ [e])		*0.85*							

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[a]) The spectroscopic factors for $l_n = 2$ have been calculated for $d_{\frac{3}{2}}$ transfer, except in the case of numbers in italic type, where $d_{\frac{5}{2}}$ transfer has been supposed.

[b]) Ref. [15]).

[c]) Ref. [16]).

[d]) Excitation energies and spin assignments are from ref. [17]), if not indicated otherwise.

[e]) From present experiment.

[f]) Compound nucleus formation only.

[g]) For spectroscopic factors of odd-parity states, see table 3.

[h]) For a discussion of possible $T = 1$ character, see text.

of a positive and a negative parity level is not excluded, in which case the $\pi = +$ component of the doublet is not excited in the proton stripping reaction and the $\pi = -$ level is not observed in the ^{35}Cl(τ, α)^{34}Cl reaction.

In ref. [1]) the level at $E_x = 4.14$ MeV was assigned $J^\pi = 2^-$, because the angular distribution from the ^{33}S(τ, d)^{34}Cl reaction showed an $l_p = 1+3$ pattern. However, in a footnote in ref. [1]) this assignment was changed to $J^\pi = 2^+$, consistent with the results of the present ^{35}Cl(τ, α)^{34}Cl investigation.

The experimental spectroscopic factors, S_n, obtained in the present experiment are displayed in table 2 and fig. 5. In fig. 5 they are compared with the results from the

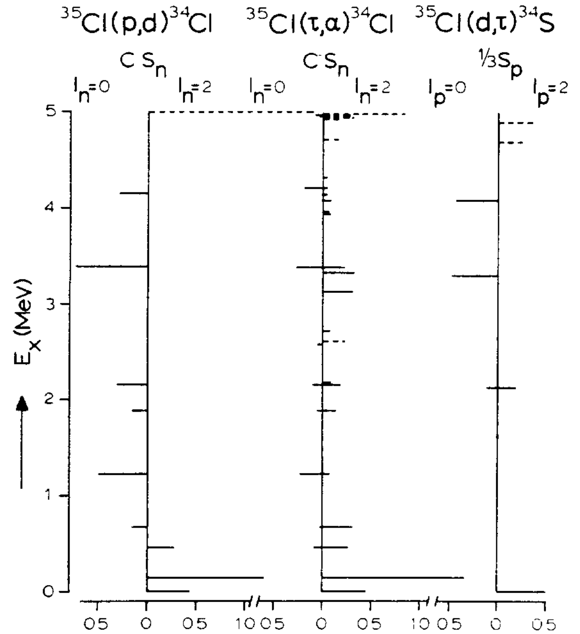

Fig. 5. Comparison of C^2S_n ($C^2 = 1$ for $T = 0$, $C^2 = \frac{1}{3}$ for $T = 1$) from the present ^{35}Cl(τ, α)^{34}Cl reaction, with C^2S_n from ^{35}Cl(p, d)^{34}Cl [ref. [2])] and with $\frac{1}{3}S_p$ from the ^{35}Cl(d, τ)^{34}S reaction. For the latter the spectroscopic factors from refs. [5,6]) were averaged. Dashed lines indicate that these spectroscopic factors have been calculated for $d_{\frac{3}{2}}$ transfer.

^{35}Cl(p, d)^{34}Cl reaction [2]). Although, due to the bad resolution of the (p, d) experiment only the levels with large S_n can be compared, the overall agreement is good.

4.2. NEW LEVELS IN ^{34}Cl

As pointed out in sect. 1, ^{34}Cl levels could be identified unambiguously from the kinematical shift of their corresponding α-particle groups in the spectrograph. In this way several hitherto unreported levels were found. These will be treated in order of increasing excitation energy.

A new level found at 3847±10 keV does not show a pick-up angular distribution. In the ^{33}S(τ, d)^{34}Cl reaction [1]) an $l_p = 3$ level was found at 3983±3 keV, it now turns out to be a doublet with components at 3964±10 and 3982±10 keV. The angular distributions show $l_n = 2$ and $l_n = 3$ character, respectively.

A relatively strong peak with an $l_n = 0+2$ angular distribution has been observed at $E_x = 4206 \pm 10$ keV. As this is the only state with a strong $l_n = 0$ component in this energy region, it is believed to be identical with the 4.16±0.02 MeV state observed with $l_n = 0$ in the ^{35}Cl(p, d)^{34}Cl reaction [2]) (fig. 5). The combination of l_n values found leads to the assignment $J^\pi = (1, 2)^+$. From arguments to be discussed in subsect. 4.3, $J^\pi = 1^+$ is most probable. This supposition is supported by the fact that no evidence for this level was found from the ^{36}Ar(p, τ)^{34}Cl reaction [3]), in which one expects only natural parity states to be populated.

An $l_n = 0+2$ angular distribution is also shown by a new state at 4321±10 keV leading to a $J^\pi = (1, 2)^+$ assignment.

A level at 4715±10 keV, which is relatively strongly excited, is found with an $l_n = 2$ angular distribution. In subsect. 4.3 it will be argued that this level should have $J^\pi = 4^+$.

From the reactions ^{35}Cl(p, d)^{34}Cl [ref. [2])], ^{36}Ar(p, τ)^{34}Cl [ref. [3])] and ^{36}Ar(d, α)^{34}Cl [ref. [3])], a strong group of levels in ^{34}Cl near 5.0 MeV excitation has been reported. Also in the present experiment such a strong multiple group appears at this position. It could be split into five separate groups at excitation energies of 4939±11, 4958±11, 4971±11, 4998±12 and 5010±13 keV. The levels at 4.94, 4.97 and 5.01 MeV show $l_n = 2$ and the levels at 4.96 and 5.00 MeV an $l_n = 0+2$ angular distribution. This limits the spin and parity of the first three to $J^\pi = (0-4)^+$ and of the last two to $J^\pi = (1, 2)^+$.

4.3. THE $T = 1$ LEVELS IN ^{34}Cl

With respect to the positions of the $T = 1$ levels, ^{34}Cl is a rather unique nucleus, because the ground state has $T = 1$, such that the $T = 1$ excited states are expected at approximately equal excitation energies in ^{34}S, ^{34}Cl and ^{34}Ar. The first three $T = 1$ excited states in ^{34}Cl are known to be at $E_x = 2.16$, 3.38 and 3.96 MeV [ref. [17])]. Below $E_x = 5$ MeV there are six more $T = 1$ levels to be expected in ^{34}Cl (see fig. 5) corresponding to ^{34}S levels at 4072.4±0.7 (1^+), 4114.6±0.7 (2^+), 4622.3±0.6 (3^-), 4687.5±0.6 (4^+), 4875.1±0.6 (3^+) and 4891±2 keV (2^+).

The (d, τ) group which corresponds to the (unresolved) 4.07+4.11 MeV doublet shows $l_p = 0$ and $S_p = 0.9$–1.2 [refs. [5, 6])]. The only ^{34}Cl excited state in this region with such a large $l_n = 0$ spectroscopic factor is the 4.21 MeV level (see fig. 5). From experimental arguments it is uncertain whether this level corresponds to the 4.07 or the 4.11 MeV level in ^{34}S. The results from recent shell-model calculations [15]) show a relatively large $l_n = 0$ spectroscopic factor for the $J^\pi = 1^+$ state while the $J^\pi = 2^+$ state has $S(l = 0) = 0$. Accordingly the ^{34}Cl(4.21 MeV) level should probably be assigned $J^\pi = 1^+$. The other $T = 1$ state in ^{34}Cl could be either the 4.08 or the 4.11 MeV level, which both have weak $l_n = 0$ components.

The lowest negative parity state in ^{34}S is the 4.62 MeV level with $J^\pi = 3^-$. The level scheme of ^{34}Cl shows in this region two states with negative parity, at $E_x = 4.61$ and 4.64 MeV. The latter is obscured in the small-angle region by the α-particle group leading to the ^{31}S(2.21) level. Moreover, the (d, τ) spectroscopic factor of ^{34}S(4.62) is not known, which makes it impossible to draw conclusions about the isospins of the ^{34}Cl 4.61 and 4.64 MeV levels.

The level at 4.72 MeV in ^{34}Cl clearly fits the requirements to be the analogue of ^{34}S(4.69) (see fig. 5). Both states have $l = 2$ with comparable spectroscopic factors.

Because the Coulomb shift of the $T = 1$ levels in ^{34}Cl considered above is on the average 40 keV upwards, the analogues of ^{34}S(4.88) and ^{34}S(4.89) with $J^\pi = 3^+$ and 2^+, respectively, are expected to be among the group of levels at $E_x \approx 5.0$ MeV. The levels ^{34}S(4.88) and ^{34}S(4.89) have not been resolved in the ^{35}Cl(d, τ)^{34}S experiment. The unresolved peak shows an angular distribution with $l_n = 2$ and $S_p = 1.2$ [refs. [5, 6]]. The levels ^{34}Cl(5.00) and ^{34}Cl(5.01) are too strong to be considered serious candidates, because the spectroscopic factors would be $S_n = 1.7$ and 2.6, respectively, if one assumes $T = 1$ and $d_{\frac{3}{2}}$ transfer. The strengths of the other three levels of the group are such that any two of them could have $T = 1$ character.

4.4. COMPARISON WITH MANY-PARTICLE SHELL-MODEL CALCULATIONS

The results of two different recent calculations, performed by Wildenthal *et al.* and described extensively in refs. [15, 16] are available to be compared with experimental data from the present investigation. The model space used in both cases consists of an inert ^{16}O core with the $d_{\frac{5}{2}}$ shell filled up to at least 10 nucleons. In the first calculation [15] which covers the range $A = 30$–35, two slightly different interactions, MSDI and FPSDI, have been used. In the second calculation [16], covering the nucleides with mass $A = 34$–38, also several interactions have been considered but the one named "11.0h+ASPE" seems to give the best results for ^{34}Cl. In table 2 where the experimental and theoretical results are compared, the notation mentioned above has been used. Because experimentally one cannot distinguish $d_{\frac{3}{2}}$ from $d_{\frac{5}{2}}$ transfer the experimental spectroscopic factors have been calculated for either $d_{\frac{3}{2}}$ or $d_{\frac{5}{2}}$ transfer

TABLE 3

Spectroscopic data for negative parity levels in ^{34}Cl from the ^{35}Cl(τ, α)^{34}Cl reaction

E_x [a]) (keV)	J^π, T [a])	l_n	S_n
3545.2±0.5	3^-	1	0.007
3632.5±1.4	5^-	3	0.030
3982.1±0.3	3^-	3	0.040
4608 ±2	$(0\text{–}3)^-$	1+3	0.007, 0.040

[a]) Excitation energies and spin assignments are from ref. [17]).

(see table 2). The ratio between the calculated DWBA cross section for $d_{\frac{3}{2}}$ and $d_{\frac{5}{2}}$, for the same excitation energy, is on the average 1.3. The theoretical spectroscopic factors from the MSDI and FPDSI calculations in general reproduce the experimental data satisfactorily. The agreement between experiment and the results from "11.0h +ASPE" is worse.

TABLE 4

Summed spectroscopic factors

	^{35}Cl(τ, α)^{34}Cl [a])	FPSDI [b])	MSDI [b])	11.0h+ASPE [c])
$\Sigma\, S_n(2s_{\frac{1}{2}}; T = 0)$	0.52	0.70	0.73 (0.83) [e])	0.54
$\Sigma\, S_n(1d\ ; T = 0)$ [d])	6.6	3.3	3.4 (4.6) [e])	3.6
$\Sigma\, S_n(2s_{\frac{1}{2}}; T = 1)$	2.1	1.8	1.8	1.2
$\Sigma\, S_n(1d\ ; T = 1)$ [d])	5.6	5.2	6.8	6.9

[a]) Present experiment.

[b]) Ref. [15]).

[c]) Ref. [16]).

[d]) For the evaluation of this quantity, see text.

[e]) See text.

Table 4 displays the summed spectroscopic factors obtained from the present experiment and from refs. [15,16]). Theoretical spectroscopic factors for levels which show $d_{\frac{5}{2}}$ transfer have been recalculated before summing as if the transfer was $d_{\frac{3}{2}}$, because, as mentioned above, they are indistinguishable in the experiment. The agreement is quite satisfactory but for one exception. The experimental sum $\sum S_n(l_n = 2, T = 0)$ exceeds the theoretical values by almost a factor of two. Thus the results of the present experiment point to a lack of $l_n = 2$ spectroscopic strength in the table [15]) for the calculated spectroscopic factors of the reaction ^{35}Cl(τ, α)^{34}Cl. The difference between the number of $l_n = 2, T = 0$ levels observed in this experiment (= 21) and the number of suchlike levels displayed in the table on spectroscopic factors in ref. [15]) (= 16) do not differ drastically. Therefore, MSDI calculations, using the Hamiltonian parameters from ref. [15]) and which included as much as ten levels of each $J^\pi = 0^+$–4^+ value, were carried out to look whether spectroscopic strength possibly was fragmented over many high-lying levels. If one takes into account the spectroscopic factors of all these levels, the theoretical calculated sum $\sum S_n(l_n = 2, T = 0)$ increases from 3.4 to 4.6, due to some levels with a rather large $S_n(d_{\frac{5}{2}})$ value, while $\sum S_n(l_n = 0, T = 0)$ does not change substantially. No theoretical evidence, however, was found for the strong levels observed in the vicinity of $E_x = 5$ MeV, of which the spectroscopic factors contribute heavily to the difference between theoretical and measured $\sum S_n(l_n = 2, T = 0)$.

An explanation of the fact that the model used does not account for the presence of these states may be the model condition that only two particles can be excited from the $d_{\frac{5}{2}}$ shell. This means that components of particle distributions with more than two holes in the $d_{\frac{3}{2}}$ shell are not present in the calculated wave functions, and thus do not contribute to the theoretical spectroscopic strength.

Finally the quantity $\sum S_n(l_n = 3) = 0.11$ (see table 3) shows that the average number of $f_{\frac{7}{2}}$ neutrons in the ground state of the target nucleus is 0.1. Apparently $f_{\frac{7}{2}}^2$ components in the ground-state wave function of ^{35}Cl are starting to become significant.

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