1.E.1:
2.C

Nuclear Physics 71 (1965) 593—605; © *North-Holland Publishing Co., Amsterdam*

Not to be reproduced by photoprint or microfilm without written permission from the publisher

LEVELS OF ^{36}Ar EXCITED IN THE ^{35}Cl(p, γ)^{36}Ar REACTION

F. C. ERNÉ and P. M. ENDT
Fysisch Laboratorium der Rijksuniversiteit Utrecht, Nederland

Received 11 March 1965

Abstract: With protons in the energy range E_p = 0.4-3.1 MeV, sixty-five resonances were found in the reaction ^{35}Cl(p, γ)^{36}Ar. About forty of these resonances were not reported earlier. The resonance energies and the resonance strengths are given. The gamma-ray spectra at the resonances were investigated with scintillation spectrometers. From single and coincidence spectra the gamma-ray branchings of most of the resonances and of thirteen lower ^{36}Ar levels were obtained. At some of the investigated resonances, gamma rays were observed from proton emission to the first and second excited state of ^{35}Cl.

E

NUCLEAR REACTIONS ^{35}Cl(p, γ), $E = 0.4-3.1$ MeV;
measured $\sigma(E_p; E_\gamma)$, $\gamma\gamma$-coin, γ-branching, resonance parameters. Enriched target.

1. Introduction

When this investigation was started very little was known about the levels in ^{36}Ar. The situation was summarized in the review paper by Endt and van der Leun ^{1}). Since then the energies of forty-one low levels up to 8.30 MeV were accurately determined by high resolution magnetic analysis experiments by Allas *et al.* ^{2}) on the ^{39}K(p, α)^{36}Ar reaction. The knowledge of the energies of these levels made the interpretation of the decay schemes, one of the objects of the present study, possible.

The proton energies of some low-energy resonances were accurately determined by Heitzmann and Wagner ^{3}). Also the decay of eight resonances in the reaction ^{35}Cl(p, γ)^{36}Ar was investigated by Lisle and Shaw ^{4}) and by Siltanen ^{5}). A combined search for levels in ^{36}Ar with the ^{32}S(α, γ)^{36}Ar and ^{35}Cl(p, γ)^{36}Ar reactions was performed by Erné and van der Leun ^{6}). An excitation curve of the ^{35}Cl(p, γ)^{36}Ar reaction with proton energies from 0.6 to 1.0 MeV is reported there.

Recent shell model studies of some properties of the lowest even parity levels in ^{36}Ar by Elliott ^{9}), Glaudemans *et al.* ^{10}) and Lovas *et al.* ^{11}) make the experimental investigation of decay modes, spins and parities of these levels attractive.

One purpose of this study is to obtain a survey of the strengths and main modes of decay of the observed ^{35}Cl(p, γ)^{36}Ar resonances. The determination of the decay of the lower levels forms the other object of this study. Resonances were chosen which decay only to a few lower levels, thereby enabling the study of the gamma branchings of these levels.

No special attention is paid to the many broad and often overlapping ^{35}Cl(p, p'γ)^{35}Cl resonances that appear at proton energies higher than 1.8 MeV. Only resonances exhibiting gamma decay or gamma and inelastic proton decay are described.

2. Experimental Technique

The measurements were performed with protons from the Utrecht 850 kV Cockcroft-Walton accelerator ($E_p = 0.4-0.85$ MeV) and from the 3 MV Van de Graaff accelerator ($E_p = 0.85-3.1$ MeV). After acceleration, the proton beam passed through a 90° deflection magnet. The magnetic field was measured through proton magnetic resonance. A liquid air cooling trap in front of the target minimized the deposit of contaminants, especially carbon, on the target. A more detailed description of the apparatus was given recently by van Rinsvelt and Smith ^{7}).

Some $BaCl_2$ targets enriched to 99.5 % ^{35}Cl were evaporated on clean tantalum backings. The ^{35}Cl was obtained in the form of NaCl from Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA. The NaCl was converted to $BaCl_2$ in the Laboratory of Inorganic Chemistry at Utrecht. The use of enriched targets is necessary since the proton capture reaction in ^{37}Cl shows many more resonances then that in ^{35}Cl. Moreover the ^{37}Cl(p, n)^{37}Ar reaction produces a strong neutron background, activating the NaI crystals. With indirect cooling, 5 keV thick targets withstood a 5 W beam about ten hours without deterioration. After proton bombardment targets are highly hygroscopic. Exposition to air usually spoils the targets.

The gamma rays were detected with two cylindrical NaI(Tl) crystals, 10 cm in diam. and 10 cm long, resolution 8 and 8.5 % for the 661 keV Cs line. The spectra were recorded on a RIDL 400-channel analyser. Single gamma-ray spectra were taken at all resonances at 55° with respect to the proton-beam direction and mostly at 7 cm distance from the target. Background measurements were performed at proton energies slightly below or above the resonances. At most resonances two to six coincidence spectra were taken in addition to single spectra. The resolution time of the coincidence circuit amounted to $2\tau = 2\ \mu$s. The method used to analyse the spectra is the "peeling procedure" as described by Endt and Heyligers ^{8}).

3. Results

3.1. YIELDS

The gamma-ray yield from a $BaCl_2$ target as a function of the proton energy is shown in fig. 1; the ^{35}Cl is enriched to 99.5 % and the channel setting is 3–12 MeV. The measurement was performed with three adjacent discriminator channels from 1.5–12 MeV to distinguish between doublets with different decay modes. Two different targets of 6 keV thickness were used to measure the curve which is shown. Most resonances were also studied with thinner targets (2 keV).

In the first column of table 1 the resonance energies are listed. The list gives a complete account of all peaks observed below 1580 keV. At higher proton energies only the strongest resonances have been investigated. The yield curve for lower proton energies (0.6–1.0 MeV) has been reported in a previous paper [6]. For the energy calibration of the magnetic field of the deflection magnet the resonance

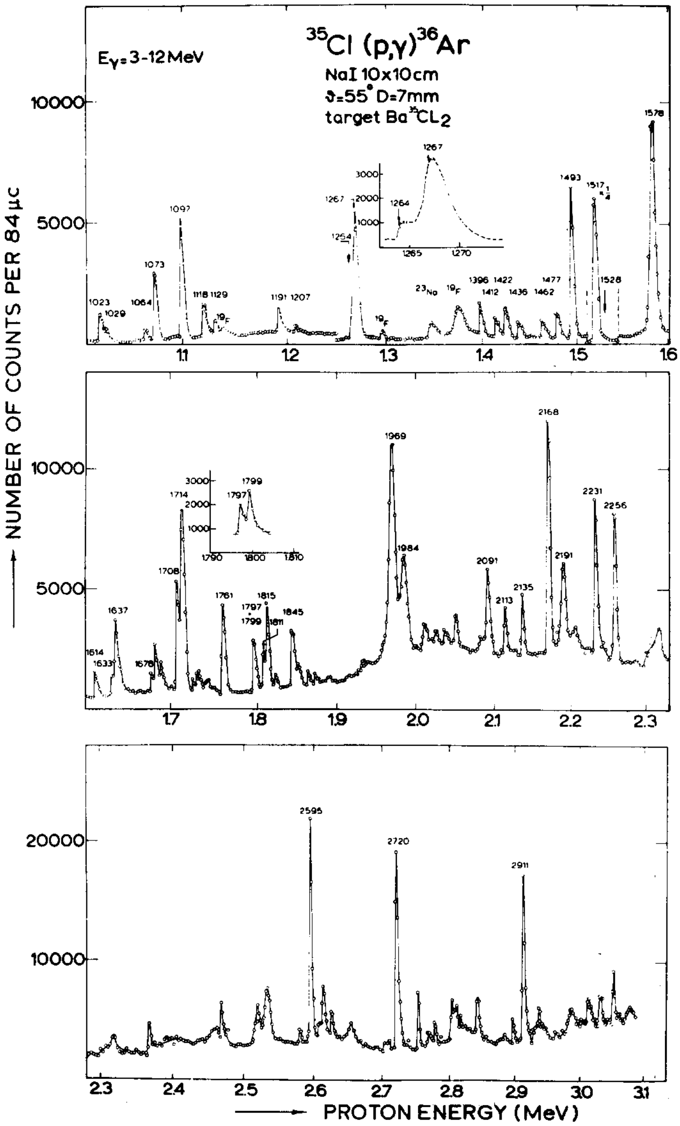
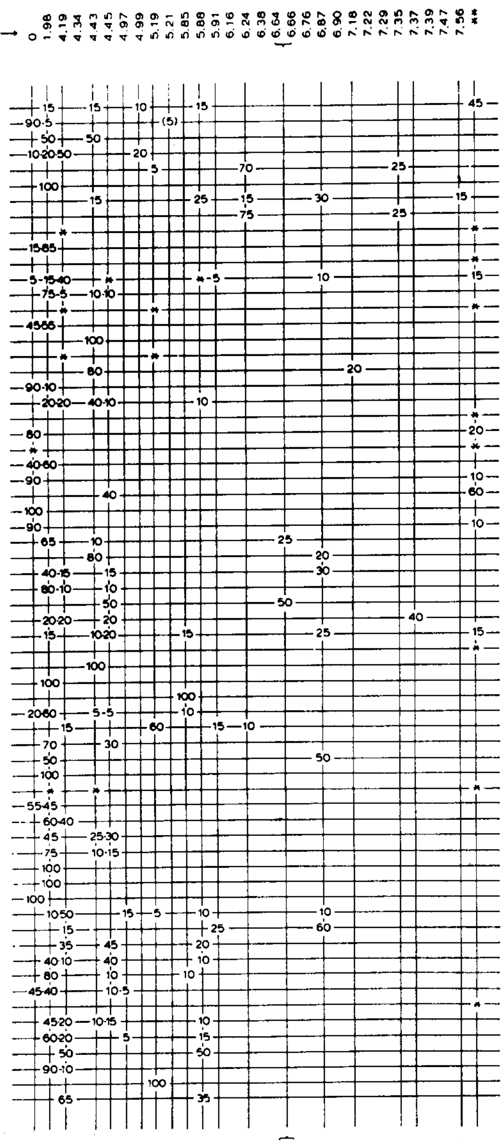


Fig. 1. Gamma-ray yield from proton bombardment of a BaCl$_2$ target enriched in ^{35}Cl. Target thickness about 6 keV.

TABLE I RESONANCES IN $^{35}Cl(p,\gamma)^{36}Ar$

PROTON ENERGIES, STRENGTHS, TOTAL WIDTHS,
EXCITATION ENERGIES, GAMMA DECAY AND PROTON DECAY.



E_p (keV)	$(2J+1)\frac{\Gamma_p\Gamma_\gamma}{\Gamma_t}$ (eV)	Γ_t (keV)	E_x (MeV)	GAMMA DECAY	PROTON DECAY P_1	PROTON DECAY P_2
2911 ±4	(16)		11.336	15 15 10 15 45	1100	450
2720 ±4	24		11.151	90-5 (5)	120	
2595 ±4	17		11.029	50 50	10	150
2256 ±3	4		10.700	10 20 50 20		
2231 ±3	8		10.675	5 70 25		
2191 ±3	2.4	7±2	10.636	100	30	
2168 ±3	8		10.614	15 25 15 30 15		
2135 ±3	2.6		10.581	75 25		
2113 ±3	(1.4)		10.560	* *		
2091 ±3	2.4		10.539	15 65		
1984 ±3	(3)	15±5	10.435	*		
1969 ±3	6	7±2	10.421	5-15 40 * *-5 10 15	210	
1845 ±3	1.4		10.300	75-5 10-10		
1815 ±3	(1.5)		10.270	* * *		
1811 ±3	0.7		10.266	45 55	35	
1799 ±3	1.0		10.255	100		
1797 ±3	(0.7)		10.253	* *		
1761 ±3	2.1		10.218	80 20		
1714 ±3	5.1		10.171	90-10		
1708 ±3	2.4		10.166	20 20 40-10 10		
1678 ±3	(0.4)		10.138	*		
1637 ±2	1.9		10.098	80 20		
1633 ±2	(0.4)		10.094	* *		
1614 ±2	0.6		10.075	40 60		
1578 ±2	6	1.5±0.3	10.040	90 10		
1528 ±2	(0.4)		9.991	40 60		
1517 ±2	1.4		9.981	100		
1493 ±2	3.7		9.957	90 10		
1477 ±2	0.6		9.942	65 10 25		
1462 ±2	0.4		9.927	80 20		
1436 ±2	0.4		9.902	40-15 15 30		
1422 ±2	0.5		9.888	80-10 10		
1412 ±2	0.3		9.879	50 50		
1396 ±2	0.4		9.863	20 20 20 40		
1267 ±2	1.2		9.737	15 10 20 15 25 15		
1264 ±2	(0.3)		9.735	*		
1207 ±2	0.2		9.679	100		
1191 ±2	0.5		9.664	100		
1129 ±2	0.3		9.606	100		
1118 ±2	0.6		9.594	20 60 5-5 10		
1097 ±2	2.7		9.574	15 60 15 10		
1073 ±2	0.9		9.550	70 30		
1064 ±2	0.18		9.543	50 50		
1029 ±2	0.14		9.507	100		
1023 ±2	(0.4)		9.501	* * *		
985.9±1.5	2.5		9.464	55 45		
968.0±1.5	0.5		9.446	60 40		
958.6±1.4	0.2		9.437	45 25-30		
897.6±1.3	6		9.378	75 10-15		
891.6±1.3	3		9.374	100		
883.5±1.3	3		9.366	100		
873.3±1.3	0.5		9.355	100		
859.7±1.3	16		9.342	10 50 15 5 10 10		
817.0±1.2	1.9		9.298	15 25 60		
772.6±1.2	0.4		9.257	35 45 20		
762.4±1.1	0.6		9.246	40-10 40 10		
754.3±1.1	0.5		9.239	80 10 10		
733.4±1.1	2.4		9.218	45 40 10-5		
704.5±1.1	(0.2)		9.190	*		
656.0±1.0	0.4		9.143	45 20 10-15 10		
643.1±1.0	0.6		9.131	60 20 5 15		
575.4±0.9	0.6		9.065	50 50		
533.0±0.8	0.7		9.025	90-10		
522.2±0.8	0.04		9.013	100		
444.0±0.7	0.3		8.938	65 35		
	ALL ±30%					

* PERCENTAGE UNKNOWN
** DECAY NOT IDENTIFIED

Errata in table 1: The resonances at E_p = 656.0, 762.4 and 859.7 keV decay to the 5.91 MeV level and not to the 5.88 MeV level.

For the resonances with proton energies equal or lower than 985.9 keV the yields are 3 times smaller than given in column two. The yield of the 1517 keV resonance is 14 instead of 1.4 eV.

The authors thank G. A. P. Engelbertink for pointing out these errors.

energies in ref. [3]), with an accuracy of 0.11 %, were used. A relativistic correction had to be applied. As additional checks the resonances from the contaminants ^{19}F and ^{23}Na were used. The resultant accuracy in the energy measurements is 0.15 %. The fourth column of table 1 gives the excitation energies of the corresponding ^{36}Ar levels. A Q value $Q_m = 8505.6$ keV was used in the calculation [1]).

The limited lifetime of the $BaCl_2$ targets complicated the resonance strength measurements. Absolute yield measurements with thick targets were performed at the 860, 1097, 1761 and 2592 keV resonances. As a next step, the yields were measured of twelve strong and isolated resonances throughout the region of investigation, relative to these primary standards. The strengths of the other resonances were obtained from comparison with the nearest secondary standard. Angular effects were approximately eliminated by taking the spectra at 55° to the beam direction. The decay schemes of the resonances were taken into account. The resonance strengths are listed in the second column of table 1. The estimated errors are 30 %. They are given between brackets if the decay scheme is not known sufficiently.

Only a few resonances have been found to be broader than the experimental width. The total width, listed in the third column of table 1, has been found by subtracting the experimental width, observed at nearby resonances, from the observed width of the broad resonance. It has been proved that this procedure is a good approximation to be preferred over the usual quadratic subtraction by comparison with exact defolding methods [12]).

3.2. DECAY SCHEMES OF THE RESONANCES

The following columns of table 1 give an account of the primary gamma rays from the decay of the resonances. The percentages are normalized to one hundred for the gamma decay, rounded off to five percent. If the decay is so incompletely known that no percentages can be given, asterisks denote the observed modes of decay. In a few cases only a 1.98 MeV gamma ray was seen distinct from the background so that no decay could be indicated in table 1. The last two columns give the relative intensities of the $E_\gamma = 1.22$ and 1.76 MeV gamma rays, produced by inelastic proton scattering on ^{35}Cl.

In table 2 the decay schemes of a number of bound levels are listed. In the first column the level energies are given that have been determined by Allas *et al.* [2]). Accurate gamma-ray energy measurements have been performed in this investigation only in those cases where they were needed to identify which level was excited. None of these measurements conflicted with the energy differences obtained from ref. [2]). In the case of the doublet at 6.64 MeV it could not be decided which member of the doublet was involved. The decay of the 6.87 MeV level is interpreted in two ways, suggesting that this level might be a doublet. The branching ratios are mainly determined from coincidence spectra. Angular correlation effects and statistics limit the accuracy.

The majority of the levels below 6 MeV was excited at one or more resonances. An exception is the 4.342 MeV level which was not excited at all. This level may be the second 0^+ state in ^{36}Ar. The second 0^+ state in self-conjugated even nuclei is usually weakly excited in resonance reactions; see for example the decay schemes [1]) of ^{24}Mg, ^{28}Si and ^{32}S.

TABLE 2

Decay of some bound levels in ^{36}Ar

Level energy (MeV)	Percentage of decay to the following levels:						
	0	1.977	4.190	4.426	4.453	4.969	5.189
1.977±0.005	100						
4.190±0.01	5±1	95±1					
4.342±0.01							
4.426±0.01	<3	100					
4.453±0.01	62±5	38±5					
4.969±0.01	<10	25±10	75±10				
4.993±0.01	79±4	16±3	5±1				
5.189±0.01	<2	5±1	81±4	14±3			
5.21 ±0.01		(100)					
5.85 ±0.01	93±2	7±2	<2	<2	<2		
5.88 ±0.01	<5	>80	<20				
5.91 ±0.01	<5	<20	>80				
6.16 ±0.01							
6.24 ±0.01	<1	<3	100				
6.38 ±0.01							
6.64 ±0.02	(20)		(40)		(40)		
6.66 ±0.02							
6.76 ±0.02							
6.87 I±0.02	<5	<10	100	<10	<10	<10	<10
6.87 II±0.02		(25)				(25)	(50)
6.90 ±0.02							
7.18 ±0.02	<5	43±5	<5	<5	57±5	<2	<5
7.22 ±0.02							
7.29 ±0.02							
7.35 ±0.03	<2	<5	<10	<10	<10	<10	100
7.37 ±0.03		(50)			(50)		
7.39 ±0.03							
7.47 ±0.03							
7.56 ±0.03			(100)				
energies taken from ref. [2])							

3.3. THE 4.190 AND 5.189 MeV LEVELS

The 4.190 MeV level is strongly excited at many resonances. It has been extensively studied in the present work at the 860 and 1097 keV resonances. A branching ratio of 95 : 5 has been obtained for the 2.21 and 4.19 MeV lines, respectively. Fig. 2 shows a coincidence spectrum taken during angular correlation measurements in a 50 h

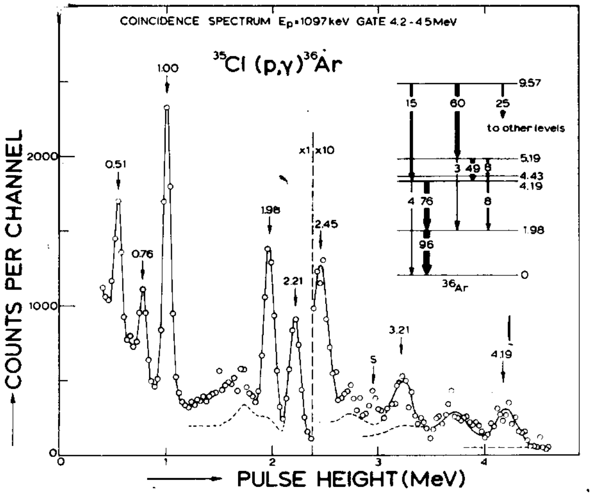


Fig. 2. Coincidence spectrum at E_p = 1097 keV (gate at 4.2-4.5 MeV, distance 10 cm), showing the decay of the 4.190 and 5.189 MeV levels. The letter S in the spectrum indicates the sum-peak of the 1.98 and 1.00 MeV lines.

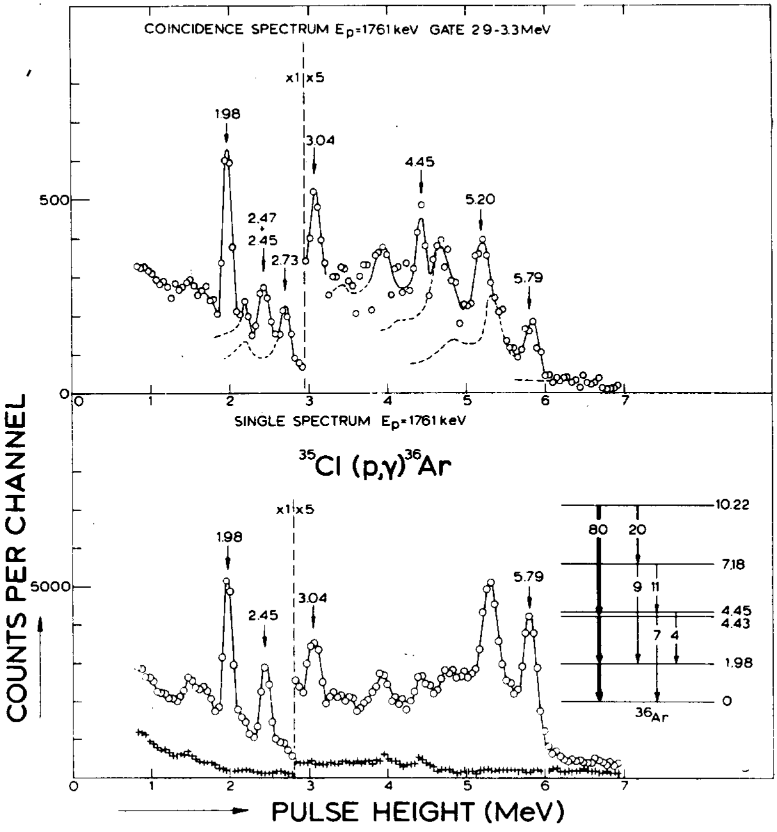


Fig. 3. Lower part: single spectrum and background at E_p = 1761 keV (distance 7 cm), showing the decay of the 4.426 MeV level. Upper part: coincidence spectrum at the same resonance (gate at 2.9-3.3 MeV, distance 4 cm), showing the decay of the 7.18 MeV level.

run. Both gamma-ray detectors were at 10 cm distance from the target; the gate was set at 4.2–4.5 MeV. In this way only pulses from the 4.38 and 5.38 MeV gamma rays gated the analyser, so that only gamma rays from the 4.190 and 5.189 MeV levels were observed. Sum-pulses account for about 25 % of the 4.19 MeV peak in the spectrum.

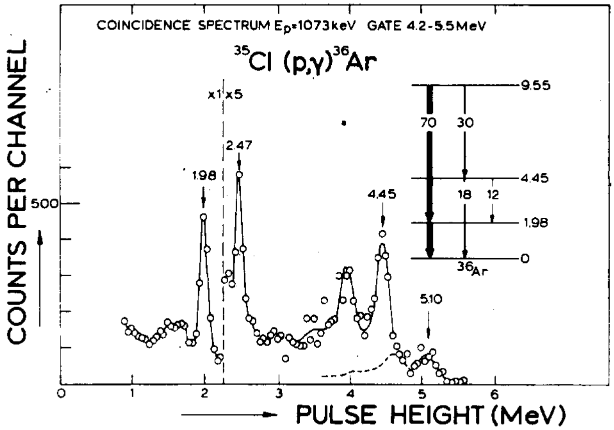


Fig. 4. Coincidence spectrum at $E_p = 1073$ keV (gate at 4.2-5.5 MeV, distance 2 cm), showing the decay of the 4.453 MeV level.

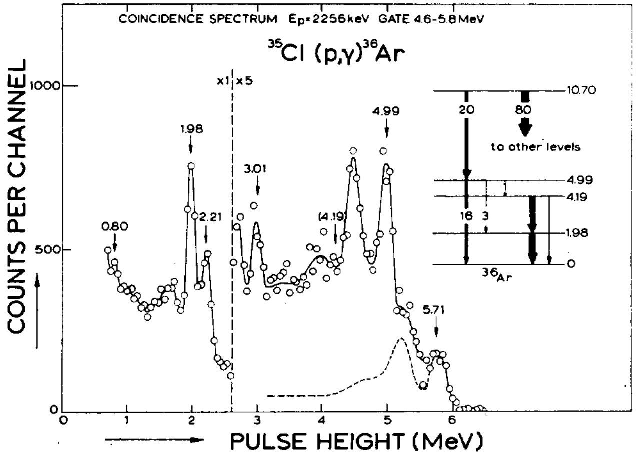


Fig. 5. Coincidence spectrum at $E_p = 2256$ keV (gate at 4.6-5.8 MeV, distance 4 cm), showing the decay of the 4.993 MeV levels.

Also the decay of the 5.189 MeV level can be easily deduced from the spectrum in fig. 2. The branching ratios of the 0.76, 1.00 and 3.21 MeV gamma rays are 14 : 81 : 5. The letter S in fig. 2 indicates the sum peak of the 1.00 and 1.98 MeV gamma rays. From the height of this peak a reliable estimate can be made of the contribution of sum-pulses from the 1.00 and 2.21 MeV gamma rays to the 3.21 MeV peak.

3.4. THE 4.426 AND 4.453 MeV LEVELS

At several resonances 2.46±0.02 and 4.44±0.03 MeV gamma rays were observed with branching ratios varying from 38 : 62 to 100 : 0. In the lower part of fig. 3 the single spectrum at the 1761 keV resonance is shown as an example of the latter extreme. Only the 1.98 and 2.46 MeV gamma rays are coincident with the 5.79 MeV line. Precise energy measurements showed that the 4.426 MeV level is excited at this resonance.

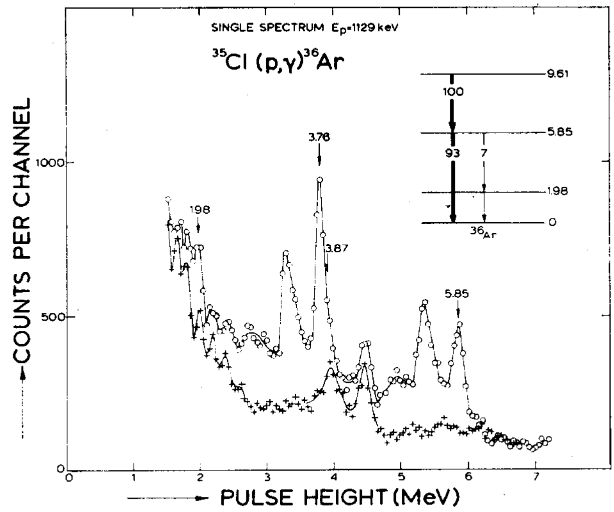


Fig. 6. Single spectrum and background at E_p = 1129 keV (distance 3.5 cm), showing the decay of the 5.85 MeV level.

The other extreme branching ratio 38 : 62 is the weighted mean of the observations at the 733 and 1073 keV resonances. In fig. 4 a coincidence spectrum is shown at the 1073 keV resonance. Only four gamma rays are coincident with the gate pulses between 4.2 and 5.5 MeV. The interpretation is shown in fig. 4. Angular correlation measurements confirm that only the 4.453 MeV level is excited at these resonances.

3.5. THE 4.969 MeV LEVEL

At the 860 keV resonance, for example, a 0.78±0.01 MeV gamma ray has been observed coincident with 4.4, 2.21 and 1.98 MeV gamma rays. The 0.78 MeV line is therefore interpreted as the decay gamma to the 4.19 MeV level. The 4.4 MeV gamma ray can be identified with the 4.38 MeV transition from the de-excitation of the resonance level to the 4.97 MeV level. A 3.01±0.03 MeV gamma ray was observed in the single spectrum and also coincident with the 1.98 MeV gamma ray. It can therefore be interpreted as the 2.99 MeV transition to the 1.98 MeV level. The intensity ratio of the 0.78 and 2.99 MeV lines in the single spectrum is about 75 : 25.

3.6. THE 4.993 MeV LEVEL

This level is excited at the 2256 and 2911 keV resonances. In fig. 5 a coincidence spectrum is shown, which was taken at the 2256 keV resonance with the gate set at 4.6–5.8 MeV. The branching ratios for the 0.80, 3.01 and 4.99 MeV transitions are 5 : 16 : 79.

3.7. THE 5.85 MeV LEVEL

The 1129 keV resonance decays only to this level. The single spectrum is shown in fig. 6. The energy measurements of the most intense gamma rays, 3.78 ± 0.03 and 5.83 ± 0.03 MeV, prove that the 5.85 MeV level is excited at this resonance. A branching ratio of 7 : 93 for the transitions to the first excited state and to the ground state has been deduced from single and coincidence spectra.

3.8. THE 5.88 AND 5.91 MeV LEVELS

These levels are frequently, and sometimes simultaneously, excited. The branching ratios for the decay to the first and second excited state, by emission of 3.9 and 1.7 MeV gamma rays, vary between 20 : 80 and 80 : 20. The resonances at 444, 575, 643, 1708 and 2168 keV showed a more intense 3.9 MeV gamma ray. The mean values obtained from the energy measurements of the 3.9 and 1.7 MeV lines at these resonances are 3.88 ± 0.03 and 1.70 ± 0.01 MeV. This indicates that mainly the 5.88 MeV level is excited here.

The resonances at 656, 762, 860 and 1097 keV have a predominant 1.7 MeV line. Energy measurements of the 3.9 and 1.7 MeV transitions yielded 3.93 ± 0.02 and 1.71 ± 0.01 MeV, indicating that mainly the 5.91 MeV level is excited at these resonances.

One can thus infer that the 5.88 MeV level mainly decays to the 1.98 MeV level and the 5.91 MeV level mainly to the 4.19 MeV level.

3.9. THE 6.24 AND 7.35 MeV LEVELS

The 2135 and 2231 keV resonances show a curious and almost identical spectrum. A single spectrum at the 2135 keV resonance is shown in fig. 7. The main decay mode is a quadrupole cascade through the 6.24, 4.19 and 1.98 MeV levels. A weaker, quintuple, cascade proceeds through the 7.35, 5.19, 4.19 and 1.98 MeV levels. The primary gamma rays in these cascades are easily recognized as such by observation of the energy increase in going from the 2135 to the 2231 keV resonance.

The 4.34 MeV line is coincident with the 2.0 and 2.2 MeV lines only, so that one may conclude that the 6.24 MeV level only decays to the 4.19 MeV level.

From intensity arguments one must conclude that the 7.35 MeV level does not decay to other levels than the one at 5.19 MeV. Coincidence spectra give lower limits for competitive decay modes.

3.10. THE 6.87 MeV LEVEL

This level seems to be a doublet. At the 860, 1064, 1267 and 1969 keV resonances a 2.67±0.01 MeV gamma ray was observed that can be interpreted as the transition to the 4.19 MeV level. For intensity reasons this must be the only decay mode. Energy measurements of the transitions to and from the 6.87 MeV level at the four resonances give a mean value of 6.854±0.010 MeV for the excitation energy of this level.

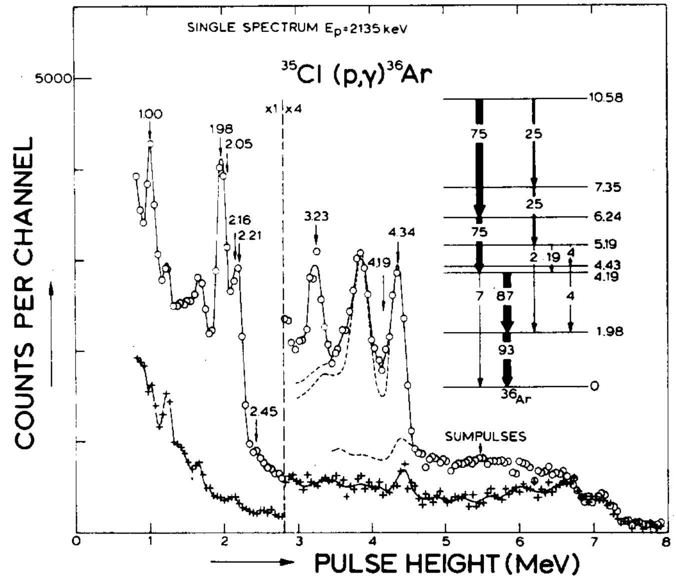


Fig. 7. Single spectrum and background at E_p = 2135 keV (distance 7 cm), showing the decay of the 6.24 and 7.35 MeV levels.

From the complicated spectra at the 817 and 2168 keV resonances one can infer that a 6.865±0.020 MeV level decays to the 5.19, 4.97 and 1.98 MeV levels. In table 2 the branching ratios obtained at the 817 keV resonance are given.

As there was no systematic energy difference between the two levels, it is improbable that the 6.90 MeV level, found in ref. [2]), is one of the levels excited at these resonances; the measurements reported here are not conclusive however.

3.11. THE 7.18 MeV LEVEL

This level is excited at the 1761 keV resonance. Coincident with a 3.05±0.02 MeV line, 5.17±0.03, 4.42±0.03 and 2.72±0.02 MeV lines were observed. A coincidence spectrum with the gate set at 2.9–3.3 MeV is shown in the upper part of fig. 3, the single spectrum in the lower part. From intensity arguments one must infer that the 3.04 MeV line represents the primary transition to the 7.18 MeV level. The branching ratio for the decay to the 1.98 and 4.45 MeV levels is 43 : 57.

3.12. THE 5.21, 6.64 (or 6.66), 6.76, 7.37 and 7.56 MeV LEVELS

These levels were only weakly excited at one or two resonances. The approximate decay modes are listed in table 2.

4. Conclusions

For proton energies below 3 MeV sixty-five resonances were assigned to the ^{35}Cl(p, γ)^{36}Ar reaction. The yields of all these resonances have been measured. From the decay schemes of these resonances the branching ratios of thirteen lower levels were determined and an estimate was made for the decay modes of five other levels.

TABLE 3

Branching ratios

Decay from	Decay to	Present work	Lisle and Shaw 4)	Siltanen 5)
Level energy (MeV)				
4.19	0	5±1	10	
	1.98	95±1	90	
4.45	0	62±5	35±10	40±15
	1.98	38±5	65±10	60±15
4.97	1.98	25±10		
	4.19	75±10	>80	
5.19	1.98	5±1		
	4.19	81±4		>70
	4.43	14±3		
5.91	1.98	<20	25±5	
	4.19	>80	75±5	
6.87 I	4.19	>80		
	4.97	<10	40	
	5.91	<10	60	
6.87 II	1.98	(25)		
	4.97	(25)	40	
	5.19	(50)		
	5.91		60	

Comparison with the branching ratios obtained from an investigation of six resonances by Lisle and Shaw 4) and of two resonances by Siltanen 5) shows reasonable agreement (see table 3). The branching ratios for the 4.19, 4.97, 5.19 and 5.91 MeV levels agree within the limits of errors. The results for the 4.45 and 6.87 MeV levels are in disagreement with our results. The branching ratios given in the present paper are thought to be more reliable because the large number of resonances investigated facilitates the selection of resonances showing a strong decay to a particular lower level under investigation.

The yields of the 1073 and 1097 keV resonances given by Siltanen ^{5}) agree within 20 % with the yields given in table 1.

The broad resonances at 1969 and 1984 keV have probably been observed as one resonance in elastic scattering experiments on natural chlorine by Rubin *et al.* ^{13}).

Comparison of the proton energy measurements of resonances in the ^{35}Cl(p, γ)^{36}Ar reaction made by several authors, has been given in ref. ^{6}).

We express our gratitude to Dr. H. A. Cysouw for converting the small amount of enriched NaCl, obtained from Oak Ridge, to $BaCl_2$.

This investigation was partly supported by the joint programme of the "Stichting voor Fundamenteel Onderzoek der Materie" and the "Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek".

References

1) P. M. Endt and C. van der Leun, Nuclear Physics **34** (1962) 1
2) R. G. Allas, L. Meyer-Schützmeister and D. von Ehrenstein, Nuclear Physics **61** (1965) 289
3) M. Heitzmann and S. Wagner, Z. Naturf. **16a** (1961) 1136
4) J. C. Lisle and P. F. D. Shaw, Proc. Phys. Soc. **76** (1960) 929
5) O. Siltanen, Soc. Sci. Fennica, Comm. Phys. Math. **29** (1964) 3
6) F. C. Erné and C. van der Leun, Nuclear Physics **52** (1964) 515
7) H. Van Rinsvelt and P. B. Smith, Physica **30** (1964) 59
8) P. M. Endt and A. Heyligers, Physica **26** (1960) 230
9) J. P. Elliott and M. Harvey, Proc. Roy. Soc. **272A** (1963) 557
10) P. W. M. Glaudemans, G. Wiegers and P. J. Brussaard, Nuclear Physics **56** (1964) 529 and 548
11) I. Lovas and J. Révai, Nuclear Physics **59** (1965) 364
12) H. Van Rinsvelt and J. Walinga, private communication
13) S. Rubin, L. E. Baily and T. O. Passell, Phys. Rev. **114** (1957) 1110