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Resonant Neutron Capture in ^{45}Sc below 100 keV

M. J. Kenny,[A] *B. J. Allen*[A] *and R. L. Macklin*[B]

[A] AAEC Research Establishment, Private Mail Bag, Sutherland, N.S.W. 2232.
[B] Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, U.S.A.

Abstract

The neutron capture cross section of ^{45}Sc has been measured with 0·2% energy resolution in the range 2·5–100 keV. Many new $l > 0$ resonances are observed and the average s- and p-wave radiative widths and standard deviations are $\langle \Gamma_\gamma \rangle_s = 0\cdot 84 \pm 0\cdot 46$ eV and $\langle \Gamma_\gamma \rangle_p = 0\cdot 5 \pm 0\cdot 3$ eV. No significant correlation is observed between the reduced neutron widths and radiative widths of the s-wave resonances.

Introduction

Recent γ-ray spectrum measurements for neutron capture in scandium in the energy range 40–430 keV showed anomalous intensities to low-lying states with large neutron angular momenta (Allen *et al.* 1976). Because statistical and valence models were found to be inadequate, a $2p$–$1h$ capture mechanism was proposed to explain the observed spectra.

Further insight into the capture mechanism may be obtained by measuring the capture cross section for a large number of resonances and searching for evidence of a correlation between the reduced neutron widths and radiative widths. An extensive program has been established for measuring neutron capture resonance parameters up to several hundred keV (Macklin and Allen 1971; Allen *et al.* 1973). In a collaborative project between ORNL and AAEC, data were obtained using the 40 m flight path facility at the Oak Ridge Electron Linear Accelerator (ORELA) and analyses were carried out at the AAEC Research Establishment.

The resonant capture cross section of ^{45}Sc for neutron energies up to 100 keV is presented here and parameters are provided for about 200 resonances. This work complements and extends the total cross section measurements of Cho *et al.* (1970) who obtained parameters for 50 s-wave resonances between 19 and 106 keV. Both neutron widths and spins were determined from a shape analysis of the cross section in terms of an R-matrix multilevel formula. Some information is also available for eight resonances below 19 keV (Mughabghab and Garber 1973).

Measurements

Capture γ-rays were detected by two nonhydrogenous C_6F_6 liquid scintillators. Events were weighted according to the observed pulse height to achieve an average detector response proportional to the total energy of the capture reaction. A 0·5 mm ^{6}Li glass scintillator, 0·5 m upstream from the capture detectors, operated as a neutron monitor in the transmission mode (Macklin *et al.* 1971). The parameterization of the ^{6}Li(n, α) cross section and the efficiency perturbation caused by the constituents of the glass have been given by Macklin *et al.* (1975). The efficiency of the capture detectors was deduced using the saturated resonance method for the 4·9 eV resonance in gold.

The target consisted of 4·79 g of ^{45}Sc with dimensions 2·66 by 5·4 by 0·1 cm corresponding to $4\cdot461 \times 10^{-3}$ atom b^{-1}. The ORELA operating conditions gave a pulse width of 4 ns at 1000 pulses s^{-1}.

Data Analysis

As with other experiments in this series, peak analysis was by means of a modified version of the ORNL/RPI code (Sullivan *et al.* 1969). Breit–Wigner single-level theory was used to generate the capture cross section, and the observed areas were fitted by an iterative process after subtraction of a calculated multiple scattering component.

The area fit yields the thin sample capture area $A_\gamma = 2\pi^2 \lambda\!\!\!^{-2} g\Gamma_\gamma \Gamma_n/\Gamma$, where g is the spin weighting factor and Γ_n, Γ_γ and Γ are respectively the neutron, radiative and total resonance widths. A shape fit can also be obtained when $\Gamma_n \gtrsim 0\cdot3\,\Gamma_R$, where Γ_R is the resolution width (0·2–0·3 % of the resonance energy). In most cases, the resonance parameter part of A_γ, denoted by $\kappa = g\Gamma_n \Gamma_\gamma/\Gamma$, provides an estimate of $g\Gamma_\gamma$. The time-dependent background is assumed to be linear beneath each resonance and a prompt background correction is made (Allen *et al.* 1975) to account for the detection of resonance-scattered neutrons. For most resonances, this correction is negligible, but for $\Gamma_\gamma/\Gamma_n < 10^{-3}$ the correction to the capture yield becomes substantial, particularly at low energies.

The ground state of ^{45}Sc is $7/2^-$ and possible capture states for both s- and p-wave capture are respectively $3^-, 4^-$ and $2^+ - 5^+$. The transmission data of Cho *et al.* (1970) include allocation of $J = 3$ or 4 in each case and assign all resonances as s-wave. The high resolution of the present capture measurements allows the observation of many additional resonances. However, for most of these we have $\Gamma_n < 0\cdot3\,\Gamma_R$ and a shape analysis is not possible. Consequently, the neutron widths remain unknown, and unambiguous l and g assignments are not possible.

Results and Discussion

The respective parameters obtained for $l = 0$ and $l > 0$ resonances are presented in Tables 1*a* and 1*b*. Most of the s-wave resonances reported by Cho *et al.* (1970) are seen in the present experiment. The neutron widths in Table 1*a* are generally taken from their results. However, in some cases a lesser value clearly gave a better fit or, alternatively, two or more resonances were seen in place of one. Other resonances in Table 1*a*, which have not previously been reported, are assigned s-wave on the basis of relatively large neutron widths obtained by shape analysis.

As the neutron energy increases, it becomes more difficult to resolve additional resonances, since the average level spacing from 3 to 100 keV is about 500 eV. It was often necessary to analyse groups of five or six overlapping resonances together, the best overall fit to the group being found by iteration. At neutron energies above 100 keV, the falloff in both neutron flux and peak cross section made it very difficult to distinguish individual resonances above the background.

Table 1*a*. s-wave resonance parameters for ^{45}Sc

The neutron widths Γ_n from the present work were used in the estimation of self-shielding and multiple scattering corrections. When not specified the values of Cho *et al.* (1970) were used. The errors in the Γ_n values listed are ~30% unless otherwise shown

Resonance energy (keV)	Resonance area (b.eV)	Cho *et al.* Γ_n (eV)	Cho *et al.* J	Present work Γ_n (eV)	Present work Γ_γ (eV)
3·300±0·015	396±40	70		80±10	0·62±0·06[A]
4·326±0·050	352±35	250		320±40	0·71±0·07[A]
6·700±0·020[B]	207±21	73		125±25	0·65±0·07[A]
8·038±0·030	168±17	160		140±30	0·64±0·06[A]
9·070±0·009	217±22	260		40±10	0·96±0·10[A]
9·080±0·040	193±30			250±50	0·82±0·12[A]
11·580±0·050	158±16	140		300±50	0·86±0·09[A]
14·820±0·015	75·3±7·5			35	0·52±0·05[A]
15·623±0·016	92·1±9·2			30	0·67±0·07[A]
19·084±0·019	86·0±8·6	60	4		0·69±0·07
20·644±0·021	86·1±8·6	60	4	100	0·83±0·12
20·933±0·200	49·2±4·9	800	3	700±200	0·60±0·20
24·010±0·024	83·1±8·3	60	3		1·087±0·109
24·315±0·024	45·5±4·6	60	4		0·462±0·046
26·925±0·027	62·0±6·2	90	4		0·900±0·090
27·900±0·028	53·9±5·4	110	3		0·811±0·081
29·480±0·029	49·0±4·9	100	4	30	0·613±0·061
29·630±0·030	51·8±5·2			50	0·723±0·072[C]
32·180±0·032	53·1±5·3	570	3		0·917±0·092
33·730±0·034	47·9±4·8	190	3	200	0·866±0·087
34·860±0·035	42·7±4·3			100	0·689±0·070[C]
35·080±0·035	28·9±2·9	280	4	150	0·543±0·054
39·980±0·040	63·9±6·4	130	4	180	1·067±0·107
40·500±0·041	75·1±7·5	100	3		1·276±0·128
40·815±0·041	29·1±3·0	110	4		0·639±0·064
43·050±0·043	46·0±4·6	170	4	100	1·068±0·107
43·215±0·043	51·8±5·2			30	1·074±0·107[C]
45·730±0·046	21·3±2·1	480	3		0·521±0·052
47·180±0·047	27·1±2·7	180	3	60	0·053±0·054
48·790±0·049	23·3±2·3	160	4	40	0·478±0·048
49·120±0·049	17·5±1·8			40	0·361±0·036[C]
51·160±0·051	46·4±4·6	840	4		1·300±0·013
51·685±0·052	14·7±1·5			40	0·352±0·035[C]
52·025±0·052	21·5±2·1			40	0·521±0·052[C]
52·330±0·052	14·9±1·5	100	3	70	0·418±0·04
53·075±0·053	10·0±1·0			40	0·248±0·25[C]
54·730±0·055	57·7±5·8	220	3	40	1·760±0·176
55·125±0·055	15·1±1·5			40	0·390±0·039[C]
57·890±0·058	17·9±1·8	220	3	35	0·487±0·049
59·110±0·059	37·3±3·7	164	3	50	1·047±0·105
60·140±0·060	24·0±2·4			40	0·681±0·068[C]
61·890±0·062	26·9±2·7	520	4		0·700±0·070
62·490±0·062	29·8±3·0	570	3		1·000±0·100
62·850±0·063	18·8±1·9			100	0·548±0·055[C]
66·000±0·066	9·3±0·9			40	0·287±0·029[C]
66·100±0·066	50·8±5·1	1040	4		1·800±0·180
67·850±0·069	46·8±4·7			75	1·504±0·150[C]
68·375±0·068	44·0±4·4			50	1·435±0·144[C]

[A] Values of $2g\Gamma_\gamma$. [B] Asymmetric resonance. [C] $g = 0{\cdot}5$ assumed.

Table 1*a* (*Continued*)

Resonance energy (keV)	Resonance area (b.eV)	Cho *et al.* Γ_n (eV)	Cho *et al.* J	Present work Γ_n (eV)	Present work Γ_γ (eV)
70·110±0·070	16·0±1·9	1690	3		0·600±0·072
71·700±0·072	53·3±6·5	410	4	150	1·606±0·210
73·200±0·073	24·0±2·9	350	3	70	0·951±0·140
73·600±0·074	8·2±1·0			60	0·281±0·028[C]
74·700±0·075	28·9±2·9	150	3	60	1·177±0·153
75·000±0·075	42·9±4·3			45	1·540±0·200[C]
77·025±0·077	16·1±2·1	250	4	50	0·522±0·068
77·500±0·078	12·0±1·6	600	3		0·498±0·063
77·925±0·078	24·9±3·0	150	4	40	0·824±0·125
79·150±0·079	24·9±3·0	200	3	100	0·827±0·125
79·800±0·500	50·6±25·0	2800	3		2·0±1·0
81·200±0·081	8·3±2·8	600	4		0·280±0·090
85·600±0·086	9·8±1·5	850	4		0·350±0·052
86·400±0·086	14·2±2·1	650	3	275	0·510±0·078
87·650±0·088	69·5±5·0			75	2·934±0·440[C]
88·600±0·089	18·9±3·0	550	3		0·900±0·140
95·940±0·096	8·0±1·2	800	3	80	0·359±0·054

[C] $g = 0·5$ assumed.

Table 1*b*. $l > 0$ resonance parameters for ^{45}Sc

The neutron width Γ_n used in the estimation of the self-shielding correction and the calculation of the $g\Gamma_\gamma$ values listed was ~0·05% of the resonance energy

Resonance energy (keV)	Resonance area (b.eV)	$g\Gamma_\gamma$ (eV)	Resonance energy (keV)	Resonance area (b.eV)	$g\Gamma_\gamma$ (eV)
2·715±0·003	7·1±0 7	0·004±0·001[A]	23·015±0·023	15·3±1·5	0·072±0·007[A]
2·737±0·003	19·9±2·0	0·011±0·001[A]	23·065±0·023	1·4±0·14	0·006±0·001[A]
3·404±0·003	133·8±13·4	0·093±0·009	23·838±0·024	7·4±0·74	0·036±0·004[A]
3·582±0·004	54·8±5·5	0·040±0·004[A]	27·190±0·027	3·0±0·3	0·017±0·002[A]
5·943±0·006	9·2±0·9	0·011±0·001[A]	28·040±0·028	20·3±2·0	0·117±0·012
7·560±0·008	4·8±0·5	0·007±0·001[A]	28·235±0·028	11·9±1·2	0·069±0·007[A]
8·558±0·009	24·6±2·5	0·043±0·004[A]	29·410±0·029	16·1±1·6	0·098±0·010
9·725±0·010	91·8±9·2	0·184±0·018	30·010±0·030	23·8±2·4	0·147±0·015
10·189±0·010	23·4±2·3	0·049±0·005[A]	31·135±0·031	14·2±1·4	0·092±0·009
10·662±0·011	182·5±18·3	0·400±0·040	32·840±0·033	10·6±1·1	0·072±0·007[A]
10·740±0·011	116·6±11·7	0·258±0·026	32·940±0·033	39·3±3·9	0·266±0·027
11·265±0·011	51·5±5·2	0·120±0·012	33·280±0·033	20·6±2·1	0·142±0·014
14·050±0·014	58·4±5·8	0·169±0·017	35·470±0·036	30·7±3·1	0·224±0·022
14·390±0·014	2·2±0·2	0·006±0·001	35·800±0·036	16·3±1·6	0·121±0·012
14·500±0·015	82·1±8·2	0·245±0·025	35·995±0·036	35·4±3·5	0·262±0·026
15·280±0·015	19·2±1·9	0·061±0·006[A]	36·310±0·036	14·4±1·4	0·107±0·011
15·763±0·016	20·5±2·1	0·066±0·007[A]	36·390±0·037	26·0±2·6	0·194±0·019
17·192±0·017	27·6±2·8	0·10±0·01	36·930±0·037	23·4±2·3	0·178±0·018
17·677±0·018	43·0±4·3	0·159±0·016	38·000±0·038	31·1±3·1	0·243±0·024
18·504±0·019	13·9±1·4	0·005±0·001[A]	38·730±0·039	22·4±2·2	0·178±0·018
19·341±0·019	4·0±0·4	0·016±0·002[A]	41·740±0·042	22·1±2·2	0·190±0·019
20·726±0·021	44·0±4·4	0·187±0·019	42·300±0·042	16·4±1·6	0·143±0·014
21·114±0·021	41·4±4·1	0·180±0·018	42·790±0·043	6·4±0·6	0·056±0·006[A]
21·580±0·022	53·7±5·4	0·238±0·024	42·900±0·043	20·3±2·0	0·228±0·023

[A] Suggested value for $g\Gamma_n$ ($\Gamma_n \ll \Gamma_\gamma$).

Table 1b (*Continued*)

Resonance energy (keV)	Resonance area (b.eV)	$g\Gamma_\gamma$ (eV)	Resonance energy (keV)	Resonance area (b.eV)	$g\Gamma_\gamma$ (eV)
43·710±0·044	5·0±0·5	0·045±0·005[A]	75·430±0·075	8·7±1·2	0·135±0·105
43·920±0·044	13·3±1·3	0·121±0·012	75·780±0·076	4·2±0·4	0·065±0·008[A]
44·080±0·044	16·4±1·6	0·149±0·015	76·420±0·076	11·0±1·4	0·173±0·019
45·300±0·045	10·7±1·1	0·099±0·010	78·215±0·078	17·4±2·0	0·280±0·032
45·570±0·046	7·1±0·7	0·066±0·007[A]	80·100±0·080	5·1±1·0	0·096±0·020
45·780±0·046	9·0±0·9	0·084±0·008	82·180±0·082	30·2±3·8	0·511±0·057
47·310±0·047	23·1±2·3	0·225±0·023	82·480±0·083	21·9±2·8	0·372±0·042
48·310±0·048	27·1±2·7	0·269±0·027	83·005±0·083	34·8±4·0	0·595±0·066
48·530±0·049	31·1±3·1	0·311±0·031	83·450±0·084	33·9±4·0	0·582±0·065
49·540±0·050	30·8±3·1	0·399±0·040	83·900±0·084	17·3±2·1	0·298±0·036
49·750±0·050	4·9±0·5	0·063±0·006[A]	84·950±0·085	13·3±1·6	0·233±0·029
50·500±0·051	16·8±1·7	0·174±0·017	85·205±0·085	11·4±1·4	0·200±0·025
50·685±0·051	12·5±1·3	0·130±0·013	85·525±0·086	5·9±0·8	0·104±0·013
51·050±0·051	16·0±1·6	0·168±0·017	85·840±0·086	9·5±1·1	0·168±0·021
54·255±0·054	26·3±2·6	0·293±0·029	86·105±0·086	10·4±1·2	0·233±0·029
54·525±0·054	15·6±1·6	0·174±0·017	86·675±0·087	11·4±1·3	0·202±0·026
54·920±0·055	26·1±2·6	0·295±0·030	90·240±0·090	15·8±1·8	0·294±0·037
56·655±0·057	6·8±0·7	0·079±0·008	90·575±0·091	33·2±4·2	0·619±0·072
57·010±0·057	24·3±2·4	0·285±0·029	90·950±0·091	20·6±2·6	0·385±0·047
58·760±0·059	29·2±2·9	0·353±0·035	91·600±0·092	20·2±2·6	0·381±0·047
59·920±0·060	20·0±2·0	0·246±0·065	92·250±0·092	1·1±0·2	0·021±0·002[A]
60·420±0·060	8·6±0·9	0·107±0·011	92·720±0·093	7·9±1·1	0·150±0·020
62·025±0·062	10·3±1·0	0·167±0·017	93·390±0·093	15·7±2·2	0·302±0·040
62·500±0·063	9·8±0·9	0·127±0·013	93·780±0·094	34·5±4·4	0·665±0·079
63·050±0·063	14·9±1·5	0·246±0·025	94·020±0·094	36·3±4·6	0·701±0·083
63·400±0·063	5·1±0·5	0·066±0·007[A]	94·450±0·094	19·0±2·5	0·370±0·047
63·850±0·064	22·5±2·3	0·296±0·030	95·250±0·095	9·6±1·3	0·187±0·023
64·780±0·065	22·1±2·2	0·294±0·030	96·440±0·096	17·0±2·4	0·337±0·040
65·520±0·066	23·3±2·3	0·314±0·031	96·900±0·097	13·5±2·9	0·270±0·035
67·050±0·067	10·4±1·0	0·143±0·014	98·260±0·098	14·5±2·1	0·293±0·036
69·555±0·070	34·4±3·4	0·492±0·049	98·585±0·099	18·8±2·5	0·382±0·047
70·375±0·071	21·7±2·5	0·314±0·033	99·080±0·099	20·3±2·7	0·415±0·055
72·115±0·072	7·0±0·9	0·104±0·011	99·200±0·099	16·2±2·3	0·331±0·043

[A] Suggested value for $g\Gamma_n$ ($\Gamma_n \ll \Gamma_\gamma$).

Errors quoted in Tables 1*a* and 1*b* are a combination of normalization errors (~5%) and those arising out of individual fits. The latter are generally about 10% for energies up to 70 keV, increasing at higher energies to about 15% because of the above-mentioned overlap. The transmission experiment of Cho *et al.* (1970) identifies a broad s-wave resonance at 79·8 keV having $2g\Gamma_n = 2450$ eV ($g = 7/16$). Careful examination of the present cross section data reveals little evidence for this resonance. However, if it is present, it can be fitted into the data using a radiative width of ~2 eV. The error on this value is ±1 eV.

Figs 1*a* and 1*b* show a plot of the observed capture cross section as a function of neutron energy covering the range 3–130 keV, and Fig. 2 shows a staircase plot of the number of s-wave levels as a function of neutron energy. A relatively uniform level spacing is seen, with about a 10% increase in slope for the second half of the energy range. The average s-wave spacing between resonances is 1·4 keV. A Porter–Thomas distribution of the ratio of individual reduced neutron widths to the average reduced

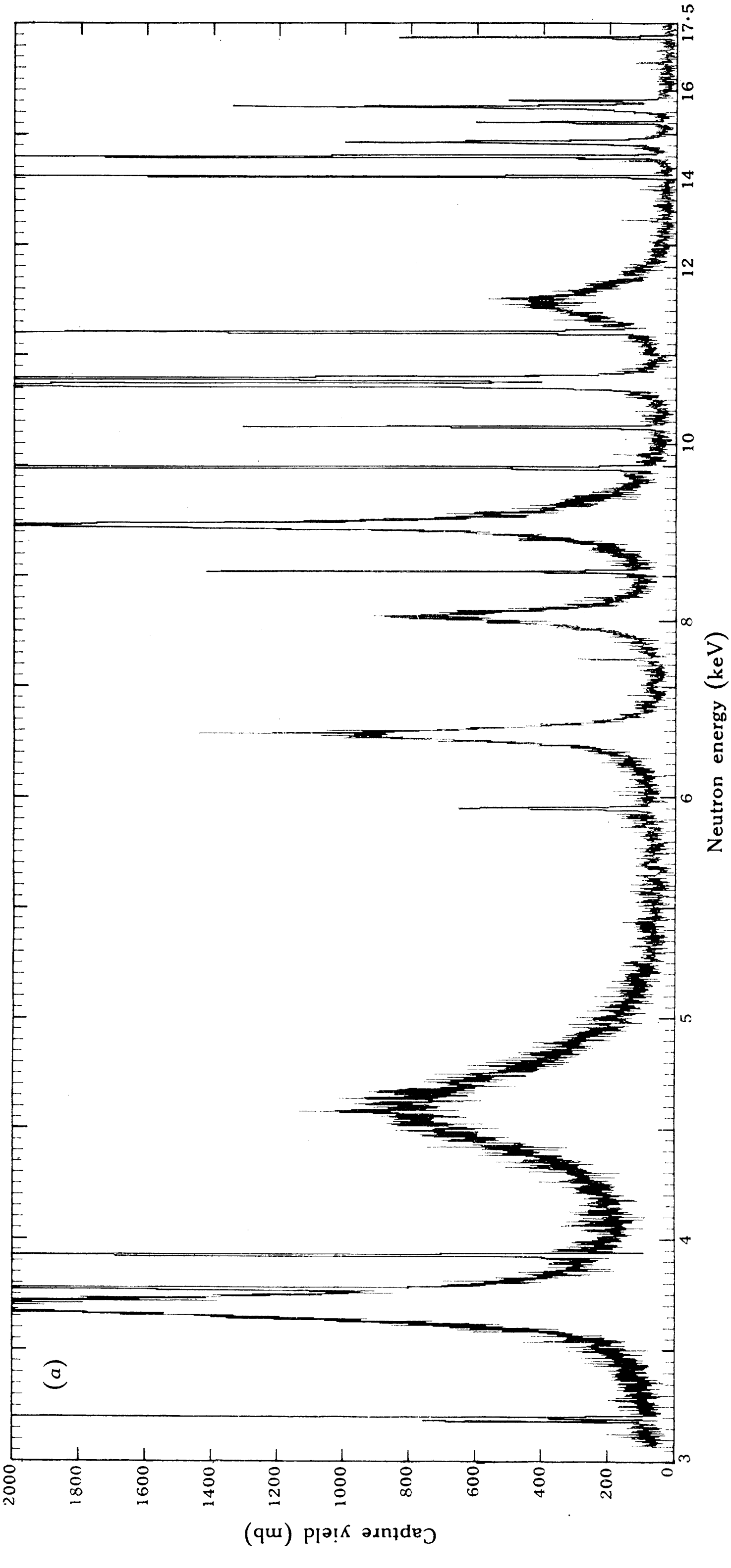

Fig. 1*a*. Uncorrected neutron capture cross section for ^{45}Sc in the energy range 3–17·5 keV.

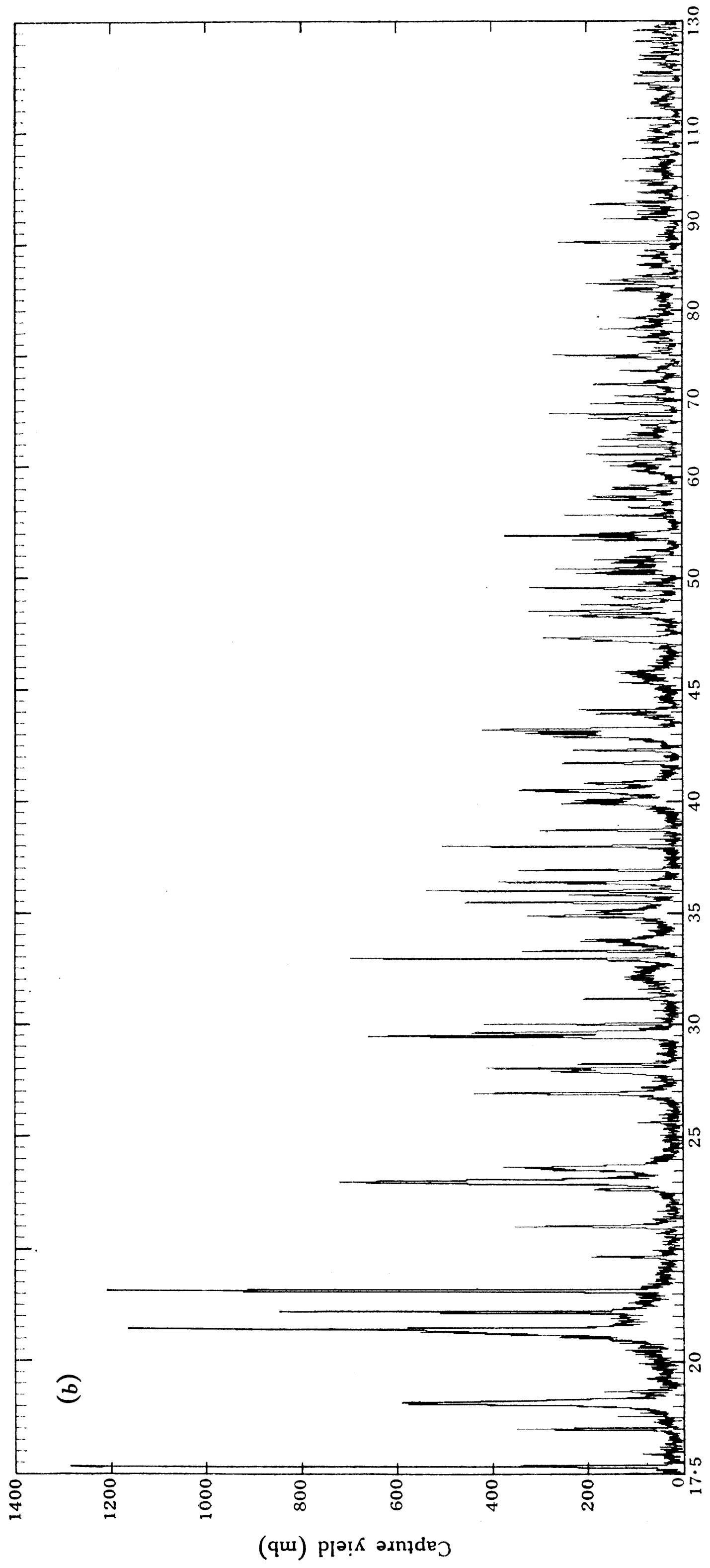

Fig. 1*b*. Uncorrected neutron capture cross section for ^{45}Sc in the energy range 17·5–130 keV.

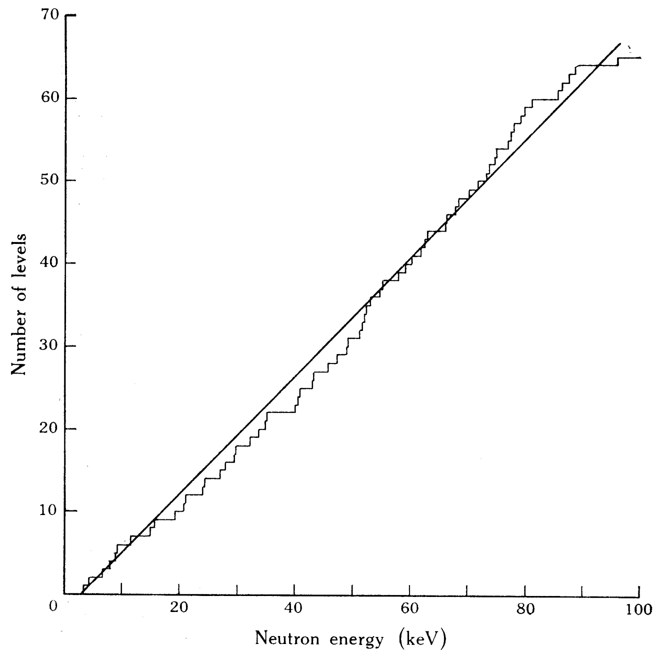

Fig. 2. Staircase plot of the s-wave level sequence for neutron capture in ^{45}Sc. The average level spacing is 1·4 keV.

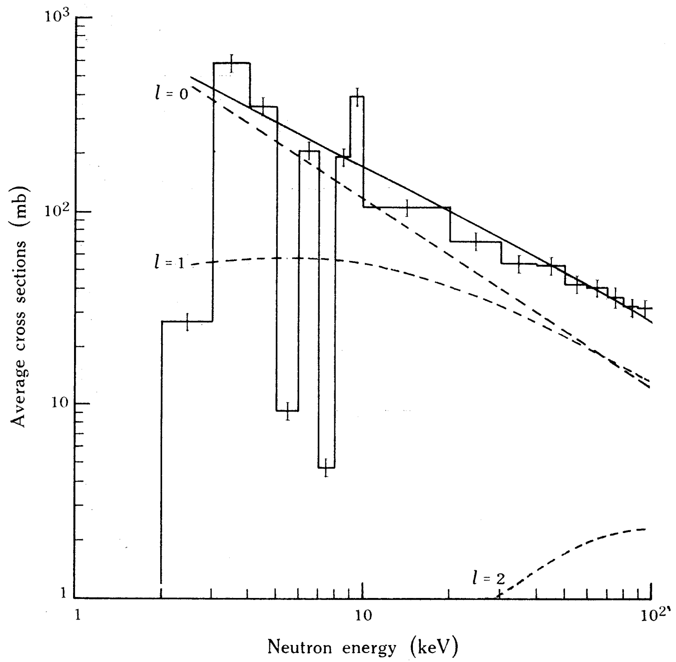

Fig. 3. Measured average neutron capture cross section for ^{45}Sc compared with the calculated s-wave, p-wave and total cross sections using the average parameters given in Table 2.

neutron width suggests a shortfall of about 10% in the number of small values. It would appear that a small fraction of resonances assigned as p-wave may actually be s-wave. The average resonance parameters derived from the data are summarized in Table 2.

The average cross section as a function of energy is given in Table 3 and compared in Fig. 3 with the s-wave, p-wave and total capture cross sections which are calculated using the average level spacings and strength functions listed in Table 2. The agreement is good, except in the region below 10 keV where a small number of large s-wave resonances cause rapid fluctuations in the cross section.

Table 2. Average resonance parameters for ^{45}Sc

The Maxwellian averaged cross section $\langle\sigma.v\rangle/v_T$ at 30 keV is $83\cdot7\pm5\cdot9$ mb and the value of $\Sigma\,(A_\gamma/E)$ $(E > 2\cdot5$ keV) is 519 ± 52 mb

l value	No. of resonances	Level spacing $\langle D\rangle_l$ (keV)	Radiative width $\langle\Gamma_\gamma\rangle_l$ (eV)	Standard deviation (eV)	Strength function S_l
0	65	1·4	0·84	0·46	$3\cdot6\times10^{-4}$
(1)	114	0·86	0·5	0·3	—

The correlation coefficient between the reduced neutron widths and radiative widths for the 65 s-wave resonances is $0\cdot21\pm0\cdot15$. The correlation was also calculated for different resonance samples with the following results: resonances below 50 keV, $-0\cdot06$; resonances above 50 keV, 0·30; omission of resonances not seen by Cho *et al.* (1970), 0·21; omission of the 79·8 keV resonance, 0·04. The correlation is thus seen to be influenced significantly by the uncertain s-wave resonance at 79·8 keV, but in no case is it large. We conclude that a significant correlation does not exist between the reduced neutron and radiative widths for s-wave capture in scandium below 100 keV.

Table 3. Average capture cross sections for ^{45}Sc

Energy range (keV)	Cross section (mb)	Energy range (keV)	Cross section (mb)
2–3	$26\cdot9\pm2\cdot7$	20–30	$70\cdot9\pm7\cdot3$
3–4	586 ± 59	30–40	$54\cdot5\pm5\cdot5$
4–5	352 ± 38	40–50	$53\cdot5\pm5\cdot4$
5–6	$9\cdot25\pm0\cdot97$	50–60	$42\cdot9\pm4\cdot3$
6–7	207 ± 21	60–70	$41\cdot2\pm4\cdot2$
7–8	$4\cdot76\pm0\cdot51$	70–80	$36\cdot8\pm4\cdot4$
8–9	193 ± 19	80–90	$32\cdot6\pm3\cdot3$
9–10	$284\pm28\cdot5$	90–100	$32\cdot2\pm3\cdot3$
10–20	$106\pm10\cdot6$		

Capture Mechanism

Allen *et al.* (1976) noted that the γ-ray spectrum after neutron capture in scandium showed a high energy bump which was insensitive to neutron energy between 40 and 230 keV. This bump corresponded to transitions to low-lying states in ^{46}Sc with $l_n = 3$. In the valence model, neutrons change state in the presence of a spectator core. Since the change in orbital quantum number is greater than one, E1 valence neutron transitions to $l_n = 3$ states following s-wave capture are forbidden by the triangle rule for the addition of angular momenta.

Of course, valence transitions are allowed to the $l_n = 1$ states above 600 keV excitation energy and the average width for these transitions can be calculated from

$$\langle \Gamma_\gamma^V \rangle_{l,J} = G Q_{lJ} \langle D_{lJ} \rangle S_l ,$$

where G is a spin weighting factor, Q is a quantity related to the sum of valence transition strengths to the $l_n = 1$ final states and S_0 and $\langle D_{0J} \rangle$ are the s-wave strength functions and the average level spacings per spin state. Allen and Musgrove (1977) have estimated Q to be $\sim 5 \cdot 1 \times 10^{-2}$. Consequently, the average valence width $\langle \Gamma_\gamma^V \rangle$ is $\sim 0 \cdot 1$ eV and contributes only 12% of the average total radiative width. If the valence component is the sole source of width correlations then the expected correlation is (Musgrove *et al.* 1976)

$$\rho(\Gamma_n^0, \Gamma_\gamma) = \frac{\langle \Gamma_\gamma^V \rangle}{\langle \Gamma_\gamma^V \rangle + \langle \Gamma_\gamma^U \rangle} \left(\frac{\sigma_V^2}{\sigma_V^2 + \sigma_U^2 + \sigma_S^2} \right)^{\frac{1}{2}} ,$$

where $\langle \Gamma_\gamma^U \rangle$ is the average nonstatistical component which is uncorrelated with the reduced neutron width ($\langle \Gamma_\gamma^S \rangle$ being the average statistical component) and the σ^2 are the appropriate variances of the distributions.

If we assume that p-wave resonances are essentially statistical, then

$$\langle \Gamma_\gamma^S \rangle \approx \langle \Gamma_\gamma \rangle_p \approx 0 \cdot 5 \text{ eV}$$

and

$$\langle \Gamma_\gamma^U \rangle \approx \langle \Gamma_\gamma \rangle_s - \langle \Gamma_\gamma^S \rangle - \langle \Gamma_\gamma^V \rangle \approx 0 \cdot 3 \text{ eV}.$$

Thus the expected correlation arising from valence transitions, namely $\rho \sim 0 \cdot 25$, is larger than the observed value. The valence process may well be present in ^{45}Sc but, because the valence radiative amplitudes are estimated to be small, width correlations and anomalous γ-ray strengths to the $l_n = 1$ states are also expected to be small, and indeed are not observed.

The anomalous transitions to the $l_n = 3$ states are also uncorrelated with the reduced neutron widths, since a 'zero' correlation is observed. Consequently, on average, these partial widths sum to $\langle \Gamma_\gamma^U \rangle$. Allen *et al.* (1976) have attributed these transitions to a $2p$–$1h$ process which may originate from doorway states near the neutron separation energy. Since Lane (1970) has shown that this correlation coefficient is inversely proportional to the number of contributing doorway states, the observed correlation implies that a large number (5–10) of such states should be present.

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