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**Research sponsored in part by ERDA under contract with Union Carbide Corporation

*Oak Ridge National Laboratory, Tennessee, USA

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ABSTRACT

Capture cross sections of the chromium isotopes have been measured at neutron energies up to 350 keV using the capture cross section facility at the 40 m station of the Oak Ridge Electron Linear Accelerator.

Parameters have been derived for 180 resonances. A moderate correlation [$\rho(\Gamma_n^0,\Gamma_\gamma) \sim 0.45$] is observed between reduced neutron widths and radiative widths for s-wave resonances. Calculations of valence widths show that valence capture can only account for the correlated component of the observed radiative widths. An additional mechanism such as a 2p-1h doorway state must therefore be occurring to explain the uncorrelated component.

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CAPTURE; CHROMIUM 50 TARGET; CHROMIUM 52 TARGET; CHROMIUM 53 TARGET; CHROMIUM 54 TARGET; CROSS SECTIONS; EXCITED STATES; GAMMA RADIATION; KEV RANGE 0-10; KEV RANGE 10-100; KEV RANGE 100-1000; RESONANCE; S WAVES; VALENCE

CONTENTS

1. INTRODUCTION

Capture cross sections of the chromium isotopes are of interest because the N=28 closed shell occurs in ^{52}Cr, and the peak in the s-wave strength function and minimum in the p-wave strength function both occur in the mass region 50-60. As the low-lying states have large spectroscopic factors, the valence model of neutron capture developed by Lane & Mughabghab [1974] is expected to be applicable. The correlations reported by Block *et al.* [1971] between the s-wave reduced neutron widths and radiative widths in this mass region support this expectation.

We report here the measurement of capture cross sections for the isotopes of chromium for neutron energies up to several hundred keV. The results partially satisfy the WRENDA requests for chromium cross sections to an accuracy of 10-20 per cent in the neutron energy range 1-400 keV.

The neutron time-of-flight facility at the Oak Ridge Electron Linear Accelerator (ORELA) was used for data taking, and the results were analysed at the Australian Atomic Energy Commission Research Establishment, Lucas Heights, as part of a collaborative project. Targets used were enriched separated isotopes in oxide form and a natural chromium metal sample.

Previous measurements for the chromium isotopes have been reported by Steiglitz *et al.* [1971] and Beer & Spencer [1974, 1975]. The former authors provided resonance parameters below 70 keV for the isotopes ^{50,52,53,54}Cr. Above this energy, information is restricted largely to parameters for ten resonances in ^{52}Cr and energies (<200 keV) of a number of resonances to an accuracy of ±1 per cent. Transmission measurements made at the same time produced neutron widths for s-wave resonances. Beer & Spencer [1974, 1975] provided information on s-wave resonances for energies below 200 keV in ^{50,52,53}Cr, and limited information on p-wave resonances. An evaluation of resonance parameters and capture cross sections for chromium up to 600 keV has been given by Abramson *et al.* [1975]. This evaluation is confined largely to ^{53}Cr and to a comparison of energy measurements.

2. EXPERIMENT

The ORELA facility provides a high neutron flux for energies up to several hundred kilovolts and high timing resolution. With a 40 metre flight path, neutron energies can be measured to within ±0.1 per cent up to 100 keV and ±0.2 per cent at higher energies.

The 40 m target station, incorporating a non-hydrogenous total energy detector for neutron capture experiments, has been described previously [Macklin & Allen 1971, Allen *et al*. 1973]. Analysis of the data followed the method described by Musgrove *et al.* [1974] and Boldeman *et al.* [1975]. Each resonance has been subjected to Monte Carlo area analysis using a modified version of the ORNL/RPI code [Sullivan *et al.* 1969]. The Monte Carlo code uses initial guesses for the resonance neutron width (Γ_n) and radiative widths (Γ_γ) to determine self-shielding and multiple-scattering corrections. An iterative fit is then made to the capture area for each resonance ($2\pi^2 \lambdabar^2 g\Gamma_n\Gamma_\gamma/\Gamma$) by varying whichever is the smaller of Γ_γ and Γ_n.

It is usually not possible to detect changes to the fit to the resonance caused by changes to Γ_n if the chosen value of Γ_n is less than about one quarter of the experimental resolution.

Details of the enriched chromium oxide and natural chromium metal targets used are given in Table 1. The thicknesses are comparable with those used by Steiglitz *et al.* [1971], but thinner by a factor of two than those used by Beer & Spencer [1974, 1975]. Although each isotope measurement can be normalised individually, a more accurate normalisation can be obtained using the ^{NAT}Cr measurements. Chronologically, the natural chromium data are much more recent than the separated isotope data and were normalised with a calibrated lithium glass monitor which was not available for the earlier runs. Since ^{NAT}Cr contains 83.8 per cent ^{52}Cr, the natural chromium run clearly showed all resonances in ^{52}Cr which are separated in energy by more than the experimental resolution from resonances in the other isotopes. In addition, about 24 resonances in the isotopes ^{50,53,54}Cr were observed. The thin metallic target resulted in less multiple scattering than with the oxides. Figure 1 shows typical portions of the spectra observed for ^{50,52,53,NAT}Cr.

The normalisation factor was obtained by comparing values of $g\Gamma_n\Gamma_\gamma/\Gamma$ from the natural data with separated isotope data. Ten resonances in each of ^{50,52,53}Cr were used, but only two in ^{54}Cr could be used. The standard deviation of the normalisation factors for the four isotopes are 8.0, 3.5, 3.4 and 6.0 per cent respectively.

3. RESULTS

The final column of Table 1 lists the maximum energies for which resonances were analysed for the isotopes ^{50,52,53,54}Cr and ^{NAT}Cr. For each isotope, this maximum energy was determined largely by statistical uncertainties. Each isotope contained evidence of numerous resonances above this value, but they were generally of irregular shape and comparable with background fluctuations. Analysis of data in these regions would result in the very real possibility of analysing 'non-resonances'. Statistical uncertainties increase at higher energies because of the fall-off in neutron flux and effective decrease in resolution. Figure 2 shows a staircase plot of p-wave levels observed as a function of neutron energy for each of the four isotopes $^{50,52,53,54}Cr$. The straight line shows the expected level density assuming uniform level spacing. In each case, a fall-off is seen in the observed level density at higher neutron energies, indicating missed levels.

Tables 2-5 list the s-wave parameters and Tables 6-9 list the ($\ell>0$)-wave parameters derived for each isotope. The values used for Γ_n in the s-wave resonances are generally those taken from Mughabghab & Garber [1973] which have been obtained in transmission measurements. Tables 2-9 list 180 resonances in $^{50,52,53,54}Cr$; previously, radiative widths were only available for one third of these. For the p-wave resonances, values are given for $g\Gamma_\gamma$, since, in most cases, the spin of the resonance is unknown. In Table 10, a comparison is made of the data from five resonances from each isotope with those obtained by Steiglitz *et al.* [1971] and Beer & Spencer [1974, 1975]. Agreement of parameters is almost always within quoted errors.

Average resonance data, average capture cross sections and 30 keV Maxwellian averaged cross sections are given for the four isotopes in Tables 11 and 12.

The following comments apply to data on individual isotopes:

Chromium-50

Problems associated with multiple-scattering and prompt-background corrections at low energies make the broad 5.64 keV s-wave resonance difficult to analyse. Table 6 contains two resonances assigned as d-wave on the basis that $\Gamma_n \ll \Gamma_\gamma$.

Chromium-52

Capture by ^{52}Cr is dominated by two large s-wave resonances at 50.3 and 98.0 keV. Each of these has a neighbouring p-wave resonance (50.2 and 95.2 keV); the parameters for these latter resonances are affected by the fit for s-wave resonance and hence have larger uncertainties than normal.

Chromium-53

The low energy portion of the spectrum is dominated by four s-wave resonances at 4.2, 5.8, 6.9 and 8.2 keV. Analysis of these resonances is particularly difficult owing to prompt background, time-dependent background, multiple scattering and possible resonance-resonance interference. An error of 50 per cent in the prompt-background correction would produce an error of 10 per cent in resonance parameters, and a 30 per cent change in time-dependent background would lead to a 15 per cent error in resonance parameters. Multiple scattering in the four resonances accounts for over half of the primary yield. An accurate analysis would require additional measurements of prompt-background corrections, followed by a multi-level fit. The results quoted are those producing the best fit after trying a wide variety of parameters. It is noted that Γ_γ values for the 5.8, 6.9 and 8.2 keV resonances are smaller than those quoted by Steiglitz *et al.* [1971]. Their parameters produce a very poor fit to our data. Errors for these resonance parameters are estimated as ~35 per cent.

The data do not contain sufficient evidence to establish that an s-wave resonance occurs at about 65.7 keV as reported elsewhere [Steiglitz *et al.* 1971, Beer & Spencer 1974, 1975].

Chromium-54

This nuclide has the least number of resonances of any of the isotopes. On the available statistics, no p-wave resonances above 200 keV could be distinguished.

4. DISCUSSION

Neutron capture data, particularly in the mass region below A=70, show a positive correlation between reduced neutron widths and radiative widths [Block *et al.* 1971, Allen *et al.* 1973, Boldeman *et al.* 1975, Allen *et al.* 1976b]. This correlation can be interpreted either as valence capture or another single particle process. From a total of 27 s-wave resonances in their data for V, Ni and Cr, Steiglitz *et al.* [1971] found a significant correlation of 0.47. For the doubly-even combined target nuclei, $^{50,52,54}Cr$, the correlation was 0.80. In their analysis of chromium data, Beer & Spencer [1974, 1975] obtained positive correlation coefficients varying from 0.64 to 0.95.

In the present experiment, the s-wave correlation coefficients for the four isotopes were found to be, respectively, (0.53 ± 0.29), (0.39 ± 0.45), (0.31 ± 0.25) and (0.67 ± 0.45) where the errors are the calculated standard deviations for the appropriate sample sizes.

4.1 Valence Calculations

Valence widths have been calculated for s-wave resonances in $^{50,52,53,54}Cr$ using the optical model code of Barrett & Terasawa [1975] which is based on the work of Lane & Mughabghab [1974]. The calculated valence widths are shown in the final columns of Tables 2-5. In every case, the valence width is much less than the radiative width. The valence width exceeds 50 per cent of the measured width in only five resonances (two in ^{50}Cr and three in ^{52}Cr).

For the 5.64 keV resonance in ^{50}Cr, the measured radiative width is 3.8 eV and the calculated valence width of 2.75 eV is in fair agreement. In the thermal capture spectrum, Kopecky [1974] calculated relative partial radiative valence widths and found them to be in good agreement with observed intensities to p-states in ^{51}Cr. He estimated that the 5.64 keV resonance accounted for about 54 per cent of the thermal cross section. Although the lack of absolute values restricts any quantitative interpretation, this resonance appears to have a significant valence component. However, valence capture cannot account for the radiative widths of most of the other resonances.

The inability of the valence model to account for the observed radiative widths is consistent with the moderate correlation coefficient and is similar to observations for neighbouring even-Z nuclei such as ^{40}Ca [Musgrove *et al.* 1976, Allen *et al.* 1976b]. In both these nuclei, moderate correlations are observed, but valence capture accounts for only a fraction (~one third) of the observed radiative widths. Capture by the odd-Z nucleus, ^{45}Sc [Allen *et al.* 1976a], shows single particle effects which cannot be accounted for by the valence model.

Capture γ-ray spectra averaged over the neutron energy range 10-80 keV have been reported for a natural chromium sample by Allen *et al.* [1969]. Transitions were observed following capture by ^{50,52,53}Cr. In each case, transitions to one or two low-lying negative parity states with strong single particle character accounted for over half of all observed transitions. This is typical of the decay process observed in keV capture by even-Z nuclei in the A=40-70 mass region and constitutes a departure from statistical processes.

Since the valence model is found to be inadequate in the chromium isotopes, an additional single particle mechanism is required to explain the data. The data for ^{45}Sc and ^{56}Fe have been interpreted partially in terms of 2p-1h doorway states across the $p_{1/2}$, $p_{3/2}$, $f_{5/2}$ and $s_{1/2}$, $d_{3/2}$ shells [Allen *et al.* 1976a,b]. A similar situation may also exist in chromium.

5. CONCLUSION

Parameters have been obtained for a larger number of s-, p- (and d-) wave resonances in the isotopes ^{50,52,53,54}Cr. Radiative widths have been derived to an accuracy of about 14 per cent.

A moderate correlation is observed between reduced neutron widths and radiative widths, but valence capture can only partially account for the observed widths. Spectral data show strong evidence for single particle effects. The behaviour is similar to that observed in calcium and iron, and an additional single particle process, such as a 2p-1h doorway interaction, is required to explain the observed data.

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TABLE 1

TARGET PARAMETERS

Isotope	Target Material	Enrichment %	Mass (g)	Atoms/barn	Oxide Atoms/barn	Maximum Neutron Energy (keV)
^{50}Cr	Cr_2O_3	90.40	4.299	0.00459	0.0076	202
^{52}Cr	Cr_2O_3	99.74	26.834	0.01549	0.0232	350
^{53}Cr	Cr_2O_3	95.56	7.105	0.00775	0.0124	265
^{54}Cr	Cr_2O_3	95.40	21.406	0.01150	0.0180	270
^{NAT}Cr	Metal	Natural	13.52	0.01051	-	350

TABLE 2

^{50}Cr s-WAVE RESONANCES

Resonance Energy (keV)	Resonance Area (b.eV)	Γ_n (eV)	Γ_γ (eV)	Γ_γ^v(calc) (eV)
5.64 ± 0.01	2870 ± 720	1665	3.8 ± 1.2	2.75
28.49 ± 0.03	89 ± 15	435	0.6 ± 0.1	0.3
36.91 ± 0.04	531 ± 80	2118	4.6 ± 1.0	1.3
55.02 ± 0.05	13.0 ± 1.5	280	0.17 ± 0.02	0.13
64.81 ± 0.06	45.0 ± 6.0	45	0.69 ± 0.10	0.02
94.46 ± 0.10	129 ± 17	2500	2.90 ± 0.40	0.81
114.71 ± 0.12	5.0 ± 0.8	120	0.17 ± 0.02	0.05
129.42 ± 0.16	52.0 ± 7.5	700	1.58 ± 0.20	0.18
156.88 ± 0.22	56.0 ± 8.0	1200	2.08 ± 0.30	0.25
168.86 ± 0.28	17.0 ± 2.5	300	0.68 ± 0.10	0.06
176.50 ± 0.31	138 ± 18	1000	5.76 ± 0.80	0.18

TABLE 3

^{52}Cr s-WAVE RESONANCES

Resonance Energy (keV)	Resonance Area (b.eV)	Γ_n (eV)	Γ_γ (eV)	Γ_γ^v(calc) (eV)
50.20 ± 0.10	89.6 ± 14.0	18	1.06 ± 0.15	0.53
97.79 ± 0.20	223 ± 35	7500	5.16 ± 0.80	1.41
121.69 ± 0.25	29.6 ± 4.5	800	0.85 ± 0.14	0.13
141.04 ± 0.16	40.2 ± 6.0	7500	1.50 ± 0.22	1.05
283.45 ± 0.38	47.2 ± 6.3	1500	3.16 ± 0.50	0.10
326.6 ± 0.44	82.3 ± 12.1	6000	6.33 ± 0.90	0.32

TABLE 4

^{53}Cr s-WAVE RESONANCES

Resonance Energy (keV)	Resonance Area (b.eV)	Γ_n (eV)	Γ_γ (eV)	Γ_γ^V (eV)
4.18±0.01	1130±260	1520	3.1 ±0.8	1.4
5.70±0.01	410±105	220	0.9 ±0.3	0.2
6.73±0.01	1016±205	1200	4.5 ±1.2	0.7
8.17±0.01	757±185	1030	2.3 ±0.6	0.6
19.72±0.02	88.5±10.0	100	0.66±0.08	0.04
25.89±0.03	24.4±2.6	150	0.40±0.05	0.04
27.36±0.03	37.6±4.0	700	0.65±0.08	0.2
29.56±0.03	61.6±6.4	250	1.15±0.14	0.07
73.18±0.07	35.4±3.8	220	1.65±0.20	0.04
86.01±0.09	27.9±3.3	180	1.52±0.18	0.03
93.80±0.09	25.5±2.9	110	1.53±0.18	0.02
95.20±0.10	9.2±1.0	75	0.55±0.13	0.01
98.54±0.10	38.7±4.0	75	2.48±0.30	0.01
104.41±0.11	51.5±5.7	30	3.18±0.50	0.01
135.15±0.15	43.8±4.7	350	4.33±0.55	0.04
163.73±0.19	44.0±4.7	500	4.59±0.58	0.04

TABLE 5

^{54}Cr s-WAVE RESONANCES

Resonance Energy (keV)	Resonance Area (b.eV)	Γ_n (eV)	Γ_γ (eV)	Γ_γ^v(calc) (eV)
23.05 ± 0.02	175.4 ± 17.5	590	0.96 ± 0.10	0.10
120.19 ± 0.15	144.5 ± 14.5	3500	4.11 ± 0.41	0.21
129.12 ± 0.16	30.8 ± 3.1	250	0.94 ± 0.10	0.014
225.8 ± 0.38	43.9 ± 4.4	400	2.35 ± 0.24	0.13
248.15 ± 0.41	40.4 ± 4.1	700	2.38 ± 0.24	0.02
267.00 ± 0.43	35.2 ± 3.5	350	2.24 ± 0.22	0.01

TABLE 6

^{50}Cr RESONANCES (ℓ>0)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_{\gamma}$ (eV)	Γ_{n} a) (eV)
5.49 ± 0.01	38.7 ± 5.0		0.048 ± 0.01
9.31 ± 0.01	27.1 ± 3.5		0.02 ± 0.005
18.64 ± 0.02	147.1 ± 19.1	0.67 ± 0.09	(10)
19.24 ± 0.02	118.2 ± 15.4	0.56 ± 0.07	(10)
24.08 ± 0.02	8.5 ± 1.1		0.02 ± 0.005
24.89 ± 0.02	55.7 ± 7.2	0.033 ± 0.04	(10)
33.47 ± 0.03	125.0 ± 16.3	1.05 ± 0.14	(8)
35.48 ± 0.03	131.4 ± 17.1	1.18 ± 0.15	(10)
35.64 ± 0.03	78.7 ± 10.2	0.72 ± 0.09	(5)
40.64 ± 0.06	71.0 ± 9.2	0.70 ± 0.09	(20)
46.75 ± 0.05	101.1 ± 13.1	1.20 ± 0.16	(10)
50.08 ± 0.05	67.3 ± 8.8	0.81 ± 0.11	(30)
53.62 ± 0.05	75.0 ± 9.8	0.99 ± 0.13	(20)
55.18 ± 0.05	27.2 ± 3.5	0.36 ± 0.05	(15)
55.56 ± 0.05	15.5 ± 2.0	0.20 ± 0.03	(25)
59.21 ± 0.06	117.3 ± 15.3	1.79 ± 0.23	(12)
63.27 ± 0.06	28.8 ± 3.7	0.45 ± 0.06	(6)
65.86 ± 0.06	73.3 ± 9.5	1.17 ± 0.15	(25)
68.25 ± 0.07	29.6 ± 3.9	0.48 ± 0.06	(40)
70.33 ± 0.07	52.0 ± 6.8	0.92 ± 0.12	(10)
73.33 ± 0.07	56.8 ± 7.4	1.00 ± 0.13	(25)
77.82 ± 0.08	62.2 ± 8.1	1.15 ± 0.15	125
79.06 ± 0.08	70.1 ± 9.1	1.32 ± 0.17	100
88.66 ± 0.09	39.0 ± 5.1	0.83 ± 0.11	(30)
90.33 ± 0.09	51.3 ± 6.7	1.11 ± 0.14	(30)

a) Bracketed values are assumed.

TABLE 6 (Continued)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_\gamma$ (eV)	Γ_n a) (eV)
98.35 ± 0.10	94.0 ± 12.2	2.22 ± 0.29	(60)
107.68 ± 0.11	66.7 ± 8.7	1.71 ± 0.22	(90)
110.81 ± 0.11	51.3 ± 6.7	1.36 ± 0.18	(50)
112.46 ± 0.12	113.0 ± 14.7	3.02 ± 0.39	200
116.00 ± 0.13	24.1 ± 3.1	0.66 ± 0.09	(40)
116.60 ± 0.13	51.0 ± 6.6	1.43 ± 0.19	(40)
121.34 ± 0.14	59.8 ± 7.8	1.73 ± 0.22	(70)
129.46 ± 0.15	45.1 ± 5.9	1.41 ± 0.18	(30)
136.80 ± 0.16	96.4 ± 12.5	3.20 ± 0.42	(60)
140.12 ± 0.16	32.3 ± 4.2	1.08 ± 0.14	(60)
141.24 ± 0.18	36.6 ± 4.8	1.23 ± 0.16	(60)
142.43 ± 0.18	51.0 ± 6.6	1.74 ± 0.23	(60)
146.92 ± 0.19	37.5 ± 4.9	1.31 ± 0.17	(60)
150.56 ± 0.20	102.1 ± 13.3	3.69 ± 0.48	120
153.00 ± 0.21	47.5 ± 6.2	1.75 ± 0.23	(50)
156.80 ± 0.22	37.3 ± 4.8	1.40 ± 0.18	(50)
162.48 ± 0.23	36.3 ± 4.7	1.39 ± 0.18	350
168.55 ± 0.24	10.8 ± 1.4	0.43 ± 0.06	(20)
186.89 ± 0.28	116.9 ± 15.2	5.23 ± 0.68	175
200.78 ± 0.32	92.7 ± 12.1	7.35 ± 0.95	100

a) Bracketed values are assumed.

TABLE 7

^{52}Cr RESONANCES ($\ell>0$)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_\gamma$ (eV)	Γ_n a) (eV)
5.27 ± 0.01	0.38 ± 0.04	0.60 ± 0.07	0.015 ± 0.005
19.30 ± 0.02	4.94 ± 0.52		0.02 ± 0.003
22.95 ± 0.02	93.8 ± 9.9	0.55 ± 0.06	(4)
27.59 ± 0.03	89.1 ± 9.4	0.63 ± 0.07	(5)
31.64 ± 0.03	25.0 ± 2.6	0.19 ± 0.02	(50)
33.91 ± 0.03	37.5 ± 4.0	0.31 ± 0.02	(6)
34.30 ± 0.03	23.4 ± 2.5	0.19 ± 0.02	(6)
47.91 ± 0.05	28.8 ± 3.1	0.34 ± 0.04	(5)
48.25 ± 0.05	35.5 ± 3.8	0.42 ± 0.06	(10)
50.08 ± 0.05	19.3 ± 2.0	0.24 ± 0.03	(4)
57.68 ± 0.06	41.0 ± 4.3	0.95 ± 0.10	(90)
68.10 ± 0.07	10.4 ± 1.1	0.17 ± 0.02	(10)
78.74 ± 0.08	20.3 ± 2.2	0.38 ± 0.04	(25)
95.00 ± 0.09	24.8 ± 2.6	0.95 ± 0.10	(30)
106.28 ± 0.11	48.9 ± 5.2	1.26 ± 0.13	(50)
109.64 ± 0.11	33.0 ± 3.5	0.88 ± 0.09	(35)
111.27 ± 0.12	1.25 + 0.13	0.20 ± 0.02	(40)
111.65 ± 0.12	5.2 ± 0.65	1.42 ± 0.15	(40)
112.89 ± 0.13	20.4 ± 2.2	0.55 ± 0.06	(40)
114.81 ± 0.13	4.8 ± 0.5	0.13 ± 0.14	(8)
115.01 ± 0.14	7.1 ± 0.8	0.20 ± 0.02	(7)
122.69 ± 0.15	59.0 ± 6.3	1.78 ± 0.19	(40)
130.42 ± 0.16	65.5 ± 6.0	1.48 ± 0.16	150
139.35 ± 0.17	58.5 ± 6.2	1.95 ± 0.21	300
143.33 ± 0.18	28.7 ± 3.0	0.82 ± 0.09	400

a) Bracketed values are assumed.

TABLE 7 (Continued)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_\gamma$ (eV)	Γ_n a) (eV)
152.76 ± 0.20	39.1 ± 4.1	1.45 ± 0.15	(55)
164.68 ± 0.21	28.5 ± 3.0	1.14 ± 0.12	(40)
183.93 ± 0.24	10.6 ± 1.1	0.47 ± 0.05	(20)
184.63 ± 0.24	20.9 ± 2.2	0.94 ± 0.10	(40)
189.91 ± 0.25	72.4 ± 7.7	3.34 ± 0.04	(120)
198.08 ± 0.27	28.1 ± 3.0	1.34 ± 0.14	(100)
199.74 ± 0.27	4.7 ± 0.5	0.22 ± 0.02	(20)
200.73 ± 0.28	33.0 ± 3.5	1.59 ± 0.17	(80)
204.53 ± 0.28	17.0 ± 1.8	0.82 ± 0.09	(100)
206.48 ± 0.30	26.6 ± 2.8	1.30 ± 0.14	(100)
224.62 ± 0.32	15.4 ± 1.6	0.86 ± 0.09	(65)
233.95 ± 0.34	13.4 ± 1.4	0.74 ± 0.08	(100)
234.65 ± 0.34	44.0 ± 4.7	2.46 ± 0.26	(130)
242.68 ± 0.35	23.7 ± 2.5	1.36 ± 0.14	200
246.37 ± 0.36	12.0 ± 1.3	0.39 ± 0.04	(25)
250.56 ± 0.37	23.7 ± 2.5	1.41 ± 0.15	(100)
304.47 ± 0.42	37.9 ± 4.0	2.76 ± 4.0	(100)
306.87 ± 0.42	30.2 ± 3.2	2.21 ± 0.23	(120)
345.31 ± 0.55	42.0 ± 4.4	3.44 ± 0.36	350

a) Bracketed values are assumed.

TABLE 8

^{53}Cr RESONANCES ($\ell > 0$)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_\gamma$ (eV)	Γ_n a) (eV)
12.11 ± 0.01	73.0 ± 7.7	0.22 ± 0.02	(8)
12.96 ± 0.01	35.9 ± 3.8	0.11 ± 0.01	(8)
14.67 ± 0.01	36.5 ± 3.9	0.13 ± 0.01	(7)
20.23 ± 0.02	69.1 ± 7.3	0.35 ± 0.04	(9)
22.49 ± 0.02	24.1 ± 2.5	0.13 ± 0.01	(18)
28.81 ± 0.03	22.5 ± 2.4	0.16 ± 0.02	(12)
28.91 ± 0.03	22.8 ± 2.4	0.16 ± 0.02	(12)
31.61 ± 0.03	37.3 ± 3.9	0.29 ± 0.03	(15)
32.17 ± 0.03	35.6 ± 3.8	0.28 ± 0.03	(16)
35.05 ± 0.04	37.2 ± 3.9	0.32 ± 0.03	(20)
37.84 ± 0.04	27.5 ± 2.9	0.27 ± 0.03	(12)
47.46 ± 0.04	20.4 ± 2.2	0.21 ± 0.02	(9)
43.32 ± 0.06	24.8 ± 2.6	0.27 ± 0.03	(9)
47.17 ± 0.05	15.4 ± 1.6	0.17 ± 0.02	(25)
47.27 ± 0.05	17.4 ± 1.8	0.20 ± 0.02	(20)
49.98 ± 0.05	22.1 ± 2.3	0.27 ± 0.03	(25)
51.08 ± 0.05	17.4 ± 1.8	0.21 ± 0.02	(35)
53.62 ± 0.05	30.1 ± 3.2	0.39 ± 0.06	(45)
62.40 ± 0.06	12.8 ± 1.4	0.19 ± 0.02	(25)
62.68 ± 0.06	31.1 ± 3.3	0.47 ± 0.05	(30)
66.48 ± 0.07	17.0 ± 1.8	0.45 ± 0.05	(50)
67.18 ± 0.07	18.3 ± 1.9	0.29 ± 0.03	(50)
69.49 ± 0.07	21.2 ± 2.2	0.35 ± 0.04	(40)
69.83 ± 0.07	55.7 ± 5.9	0.95 ± 0.10	(40)

a) Bracketed values are assumed.

TABLE 8 (Continued)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_{\gamma}$ (eV)	Γ_n a) (eV)
74.43 ± 0.08	58.1 ± 6.1	1.73 ± 0.18	200
100.64 ± 0.10	19.7 ± 2.1	0.50 ± 0.05	100
108.72 ± 0.12	68.8 ± 7.3	1.78 ± 0.19	300
116.95 ± 0.13	19.0 ± 2.0	0.54 ± 0.06	(20)
124.77 ± 0.14	25.2 ± 2.7	0.76 ± 0.08	(30)
127.57 ± 0.14	23.7 ± 2.5	0.72 ± 0.08	(50)
145.27 ± 0.17	20.1 ± 2.1	0.69 ± 0.07	(90)
147.47 ± 0.17	13.4 ± 1.4	0.47 ± 0.05	(30)
154.20 ± 0.19	34.8 ± 3.7	1.33 ± 0.14	(30)
162.98 ± 0.21	20.6 ± 2.2	0.82 ± 0.09	(30)
169.76 ± 0.23	14.8 ± 1.6	0.61 ± 0.06	(30)
176.29 ± 0.26	32.9 ± 3.5	1.44 ± 0.15	(30)
200.48 ± 0.31	7.06 ± 0.8	0.33 ± 0.03	(100)
201.67 ± 0.31	42.4 ± 4.5	2.07 ± 0.22	(100)
203.17 ± 0.32	36.7 ± 3.9	1.79 ± 0.19	(100)
234.09 ± 0.35	40.7 ± 4.3	2.31 ± 0.24	(100)
249.84 ± 0.38	23.5 ± 2.5	1.46 ± 0.15	300
264.31 ± 0.40	12.6 ± 1.3	0.81 ± 0.09	(30)

a) Bracketed values are assumed.

TABLE 9

^{54}Cr RESONANCES ($\ell>0$)

Resonance Energy (keV)	Resonance Area (b.eV)	$g\Gamma_\gamma$ (eV)	Γ_n a) (eV)
10.29 ± 0.01	65.9 ± 6.6	0.16 ± 0.02	(4)
14.45 ± 0.01	78.5 ± 7.9	0.27 ± 0.03	(6)
19.21 ± 0.02	59.5 ± 6.0	0.28 ± 0.03	(8)
51.13 ± 0.05	26.0 ± 2.6	0.32 ± 0.03	(13)
54.92 ± 0.05	23.1 ± 2.3	0.30 ± 0.03	(39)
67.39 ± 0.07	35.8 ± 3.6	0.58 ± 0.06	(16)
76.31 ± 0.08	23.8 ± 2.4	0.43 ± 0.04	(35)
163.76 ± 0.23	22.4 ± 2.2	0.88 ± 0.09	(50)
170.36 ± 0.24	21.3 ± 2.1	0.88 ± 0.09	(20)
187.31 ± 0.27	33.0 ± 3.3	1.47 ± 0.15	(100)

a) Bracketed values are assumed.

TABLE 10

COMPARISON OF DATA

Isotope	Neutron Energy (keV)	$K = g\Gamma_n\Gamma_\gamma/\Gamma$ (eV)		
		This Experiment	Steiglitz et al. [ref. 1971]	Beer & Spencer [ref. 1974,1975]
^{50}Cr	18.64	0.67±0.07	0.660±0.110	0.57±0.09
	24.08	0.34	0.365±0.060	0.31±0.06
	33.47	1.05±0.14	0.992±0.150	0.85±0.12
	40.64	0.70±0.09	0.884±0.125	0.86±0.13
	59.21	1.79±0.23	1.12±0.165	1.05±0.16
^{52}Cr	22.95	0.55±0.06	0.569±0.90	0.44±0.06
	33.91	0.31±0.02	0.336±0.056	0.26±0.04
	78.74	0.38±0.04	0.380±0.065	0.39±0.06
	111.65	1.39±0.15	1.349±0.230	
	130.42	1.48±0.16	1.328±0.230	1.34±0.20
^{53}Cr	12.11	0.22±0.02	0.185±0.031	0.17±0.04
	20.23	0.35±0.04	0.385±0.070	0.47±0.05
	35.05	0.32±0.03	0.320±0.065	0.27±0.03
	42.46	0.21±0.02	0.210±0.040	0.31±0.04
	43.32	0.27±0.03	0.200±0.038	0.29±0.004
^{54}Cr	10.29	0.16±0.02	0.143±0.022	
	14.45	0.27±0.03	0.281±0.040	
	19.21	0.28±0.03	0.256±0.038	
	51.13	0.32±0.03	0.342±0.050	
	54.92	0.30±0.03	0.355±0.055	

TABLE 11

AVERAGE RESONANCE DATA FOR Cr

	^{50}Cr		^{52}Cr		^{53}Cr		^{54}Cr	
	$\ell = 0$	$\ell = 1$	$\ell = 0$	$\ell = 1$	$\ell = 0$	$\ell = 1$	$\ell = 0$	$\ell = 1$
$\langle D \rangle$ (keV)	18.7	4.15	56.0	6.7	8.2	4.8	55.8	20.6
$10^4 S_\ell$	3.64		2.19		2.6		0.73	
$\langle \Gamma_\gamma \rangle_\ell$ (eV)	2.29	0.83	3.23	0.61	2.08	1.04	2.16	0.36

TABLE 12

AVERAGE CAPTURE CROSS SECTIONS (mb)

Energy (keV)	^{50}Cr	^{52}Cr	^{53}Cr	^{54}Cr
4 - 5			1050 ± 282	
5 - 6	2910 ± 782		619 ± 155	188 ± 471
6 - 7			1060 ± 285	
7 - 8				
8 - 9			1050 ± 263	
9 - 10	27.10 ± 7.2			
10 - 20	29.7 ± 7.4	0.51 ± 0.13	23.4 ± 5.9	6.0 ± 1.5
20 - 30	15.3 ± 3.9	17.0 ± 4.25	26.2 ± 6.8	17.5 ± 5.0
30 - 40	87.5 ±22.0	8.62 ± 2.16	13.8 ± 3.5	
40 - 50	17.4 ± 4.4	6.51 ± 1.63	7.8 ± 2.1	
50 - 60	32.8 ± 8.5	17.4 ± 4.4	7.0 ± 1.9	4.9 ± 1.3
60 - 70	17.6 ± 4.5	1.05 ± 0.20	10.0 ± 2.8	3.6 ± 1.0
70 - 80	24.3 ± 6.7	2.03 ± 0.51	14.9 ± 3.9	2.4 ± 0.6
80 - 90	39.0 ±12.7		2.8 ± 0.82	
90 - 100	27.4 ± 7.4	25.0 ± 6.3	7.4 ± 2.1	
100 - 150	14.3 ± 3.6	7.9 ± 2.0	5.5 ± 1.5	3.5 ± 1.3
150 - 200	11.2 ± 3.0	3.9 ± 1.0	2.9 ± 0.9	1.5 ± 0.4
200 - 250		3.6 ± 0.9	2.5 ± 0.7	1.7 ± 0.5
250 - 300		1.3 ± 0.3		
300 - 350		4.5 ± 1.1		
$\frac{\langle\sigma \cdot v\rangle}{v_T}$ (30 keV)	48.7 ±12.2	9.1 ± 2.1	54.0± 9.4	6.2 ± 1.5

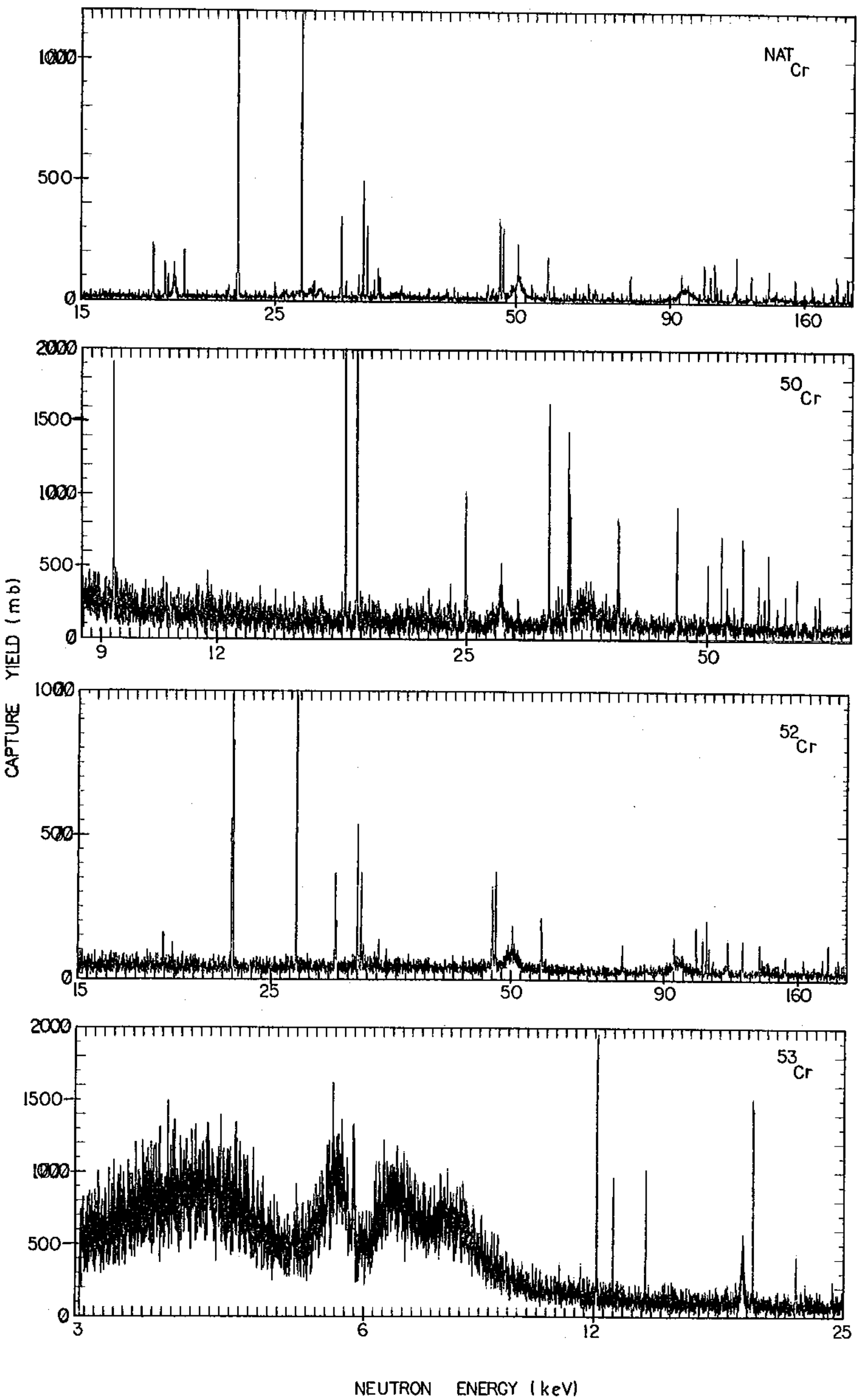

FIGURE 1. PLOTS OF SECTIONS OF SPECTRA OBSERVED FOR NAT 50,52,53 Cr.

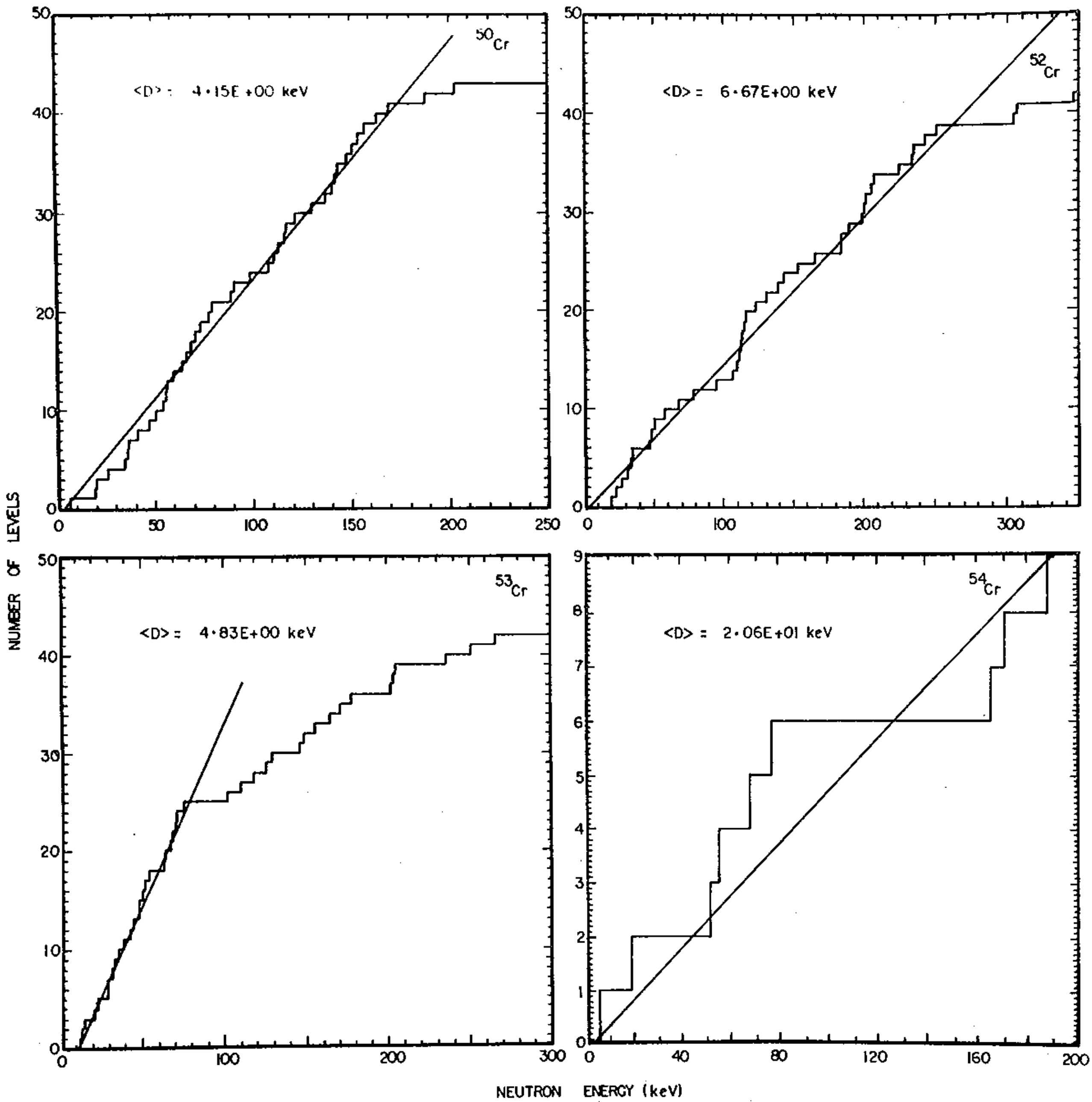

FIGURE 2. STAIRCASE PLOT OF OBSERVED LEVELS VERSUS NEUTRON ENERGY FOR $^{50,52,53,54}Cr$.