Nuclear Data for Science and Technology (1988 MITO), 779- 782, Copyright © 1988 JAERI.

DISCONTINUITIES IN THE LEVEL SPACINGS OBSERVED WITH ^{52}Cr+n RESONANCES

Gert H. Rohr, Richard C. Shelley and Antonio A. Brusegan
Commission of the European Communities, Joint Research Centre
Central Bureau for Nuclear Measurements, Geel, Belgium

Freddy A. Poortmans and Louis W. Mewissen
SCK-CEN, Mol, Belgium

Abstract: The total neutron cross section of ^{52}Cr has been measured using the neutron time-of-flight technique at the pulsed electron linear accelerator (GELINA) of CBNM, Geel. Data analysis has been performed over the neutron energy range 1keV to 1MeV with an R-matrix multilevel multichannel code to determine the resonance parameters. The following non-statistical effects in the level spacings are indicated in the resonance parameter set: two gaps are observed in the s-wave level distribution, where at least two resonances for each gap are missing; a strong discontinuity in the level spacing is observed for p-wave resonances whereby three energy ranges, up to 600keV, with different level spacings may be distinguished. This energy dependent behaviour of the p-wave level density causes parity dependence of nuclear states in the range (200-600)keV. The p-wave strength function is constant except for the strong local enhancement of the level spacing at 250keV. These deviations in the resonance parameters from statistical behaviour may be explained by doorway structures with a small spreading width, as has been observed for ^{28}Si and ^{32}S which, like ^{52}Cr, have a multiple of four nucleons in the target nucleus.

(^{52}Cr+n: Transmission Measurement, Energy Dependent Spacings,)
(Widths Distributions, Strength Functions.)

Introduction

The cross section of ^{52}Cr is important for reactor applications because this nuclide, after ^{56}Fe, is the next major component of stainless steel which is used as a structural material. The resonance data are also of significant physical interest because this nucleus has a relatively small number of protons (24) and neutrons (28) with a closed neutron shell. Therefore the level density of states at neutron separation energy is small (30 states per MeV) and according to level density systematics[1] the number of particles (p) and holes (h), i.e. quasi-particles, participating in the excitation process is either 2p-1h or maximum 3p-2h.

Recently, resonance data for ^{53}Cr and ^{55}Cr have been published[2] up to an energy of 900keV. In both nuclei parity dependences for s- and p-wave resonances have been observed. The goal of the present measurement is to substantially improve the resolution of the total cross section measurement and to extend the data set to 1MeV.

Experiment and Data Analysis

The measurements were performed at the 150MeV Geel linac (GELINA), operating with a burst width of 4.5ns and a frequency of 800Hz, using neutron flight paths with lengths of 50m, 200m and 400m. The samples used were chromium-oxide (Cr_2O_3) powder enriched to a purity of 99.74% and obtained on loan from the ORNL Isotope Division. The powder was canned in thin aluminium containers of 8cm diameter (for the 50m transmission measurement) and 3.5cm diameter with 0.0114 and 0.0593 chromium atoms/barn respectively. More experimental detail is to be published elsewhere[3].

The neutron transmission spectra of the 50m experiment have been analysed in the energy range up to 100keV by FANAL[4], a shape fitting computer program which incorporates an R-matrix formalism for the s-wave resonances and correctly takes into account strong interferences. The two other transmission measurements have been analysed in the energy range 90keV - 1MeV by the Reich-Moore multilevel program MULTI[5]. Neutron widths were determined from the shape analysis whilst spin and parity could be assigned as follows:

1. s-wave resonances were easily detected because of the strong resonance potential interference effect,
2. assignment of l=1 or l=2 could be done on the basis of the resonance shape whereby l=1 resonances show asymetric shape due to interference with p=wave scattering, whereas l=2 resonances do not,
3. spin assignment was based upon the peak total cross section,
4. in certain cases l and J assignment was possible on the basis of observed resonance-resonance interference.

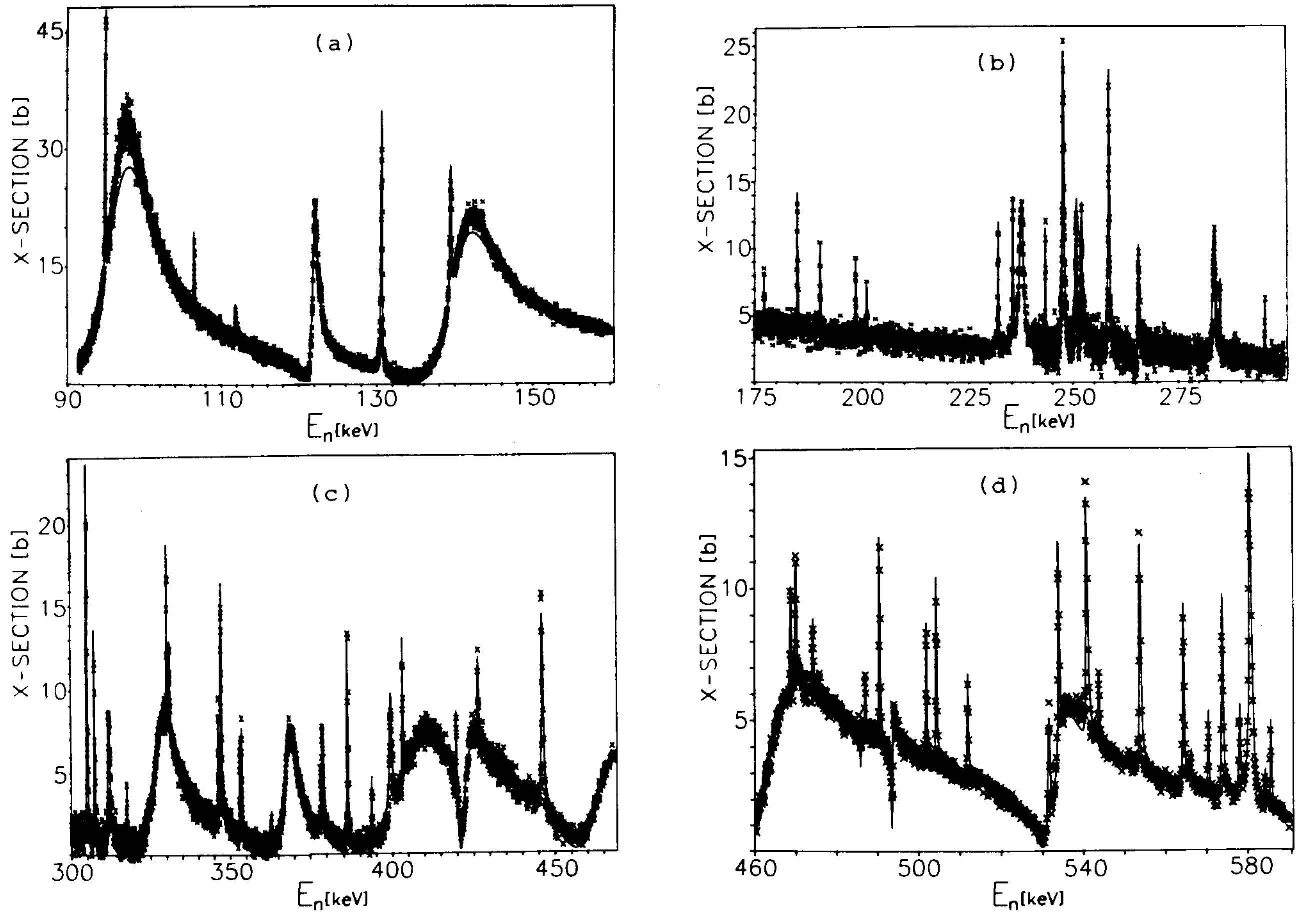
The experimental spectra were corrected for background, dead-time and the influence of the oxygen cross section and then reduced to pure transmission spectra.

Discussion of Results

A part of the multi-level fit of the total neutron cross section is given in Figs.1a-1d. The resulting resonance parameters are to be published elsewhere[3] and compared with recent data of ORNL[2] which was, until now, the most comprehensive data set available.

Resonance Parameters

The analysis of the transmission data has been extended to 1MeV and can be compared with ORNL results up to 910keV wherein they assign twenty resonances as s-waves, three of which we assign as p-waves; namely 251, 653 and 766keV. Although we assign an additional three resonances in this energy range as s-waves, giving a total of twenty up to 910keV, the resulting plot of the level distribution shown in Fig.2 is not as linear as might be expected. Two apparent gaps



Figs.1a-1d: Multi-Level Fits to Total Neutron Cross Section Measurements of ^{52}Cr.

occur, (140-265)keV and (612-740)keV, within which lie two of the three discrepant resonances mentioned. The 251keV resonance is larger than that at 258keV but no interference effect is observable. The resonance at 653keV lies on the tail of that at 617keV and should result in strong interference were they both s-waves. We have therefore not assigned these three resonances with l=0. The three additional s-wave resonances at 493, 868 and 888keV are a consequence of the improved resolution of the present measurement for they are not to be seen in the ORNL data. Whilst refering to ORNL it should be noted that in ref.2 the distribution of s-wave resonances given in their Fig.3 is not consistent with their Table II because resonances at 31, 251 and 766keV are not included in the plot.

When comparing resonances with l>0 we do not see any indications in our data at 5.2, 183, 382, 536, 616, 683, 711, 757, 761 or 906keV. Comparison with other published data for all discrepant resonances shows Beer and Spencer[6] assigning the 251keV level as s-wave and Allen[7] assigning the 5.2, 183 and 251keV levels with l>0. All other discrepant levels are not noted.

Further comparison with ref.2 shows our resonance energies of well resolved sharp peaks to be systematically 0.1% higher, although it should be noted that ORNL have since made a slight correction to their flightpath length[8]. For s-wave levels our quoted values of $g\Gamma_n$ are generally larger up to 533keV, above which the reverse is true. A similar comparison for l>0 resonances certainly shows considerable fluctuations although only in the energy range (450-600)keV is a systematic discrepancy noted.

Average Level Spacings and Widths Distribution

s-waves. In Fig.2 the number of s-wave resonances is plotted against neutron energy and two interruptions are notable in the curve, each gap representing at least two missing levels. The gap at 200keV is also observed in the ORNL data, whereas that at 650keV is not. This is due to our assignment of the resonance at 655keV as p-wave.

For the first time a level distribution is seen to deviate from linearity which, from our experience of resonance data of iron[12], cannot be explained by missed resonances. The probability of having two such gaps has been estimated, by means of a Monte Carlo code based on a Wigner distribution, as 0.2% up to 1MeV. The probability

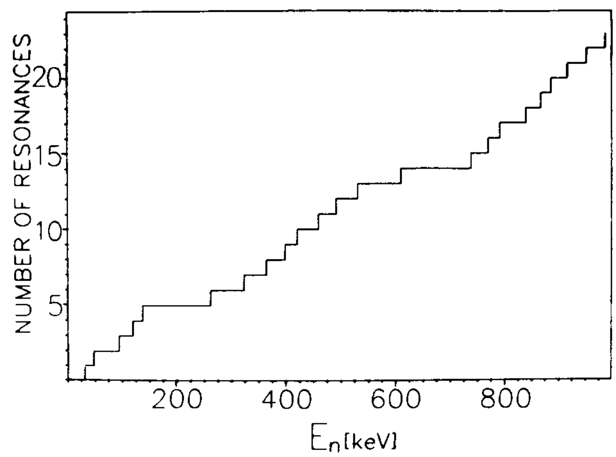


Fig.2: Level distribution for $l=0$ resonances of ^{52}Cr.

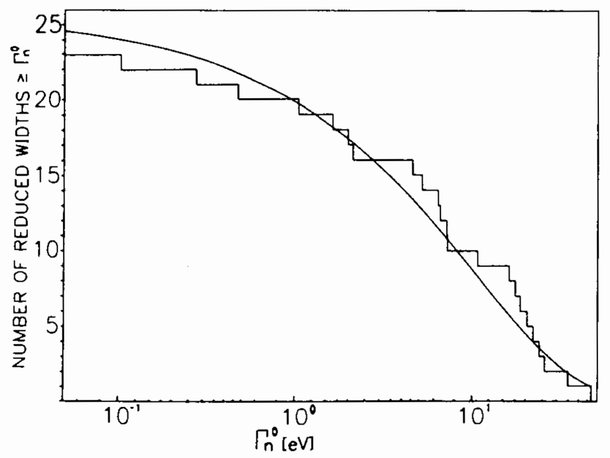


Fig.3: Histogramme of reduced neutron widths for twenty three s-wave resonances of ^{52}Cr fitted with a Porter-Thomas distribution over the energy range up to 1MeV.

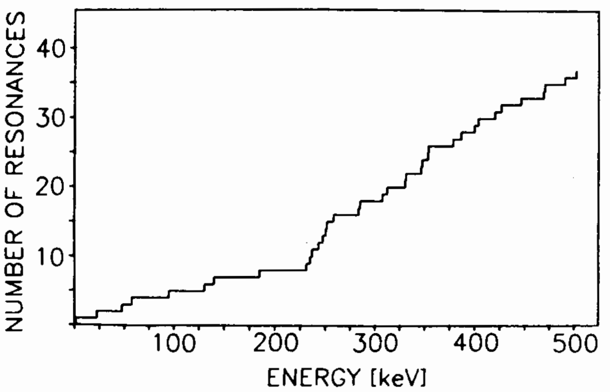


Fig.4: Level distribution for $l=1$ resonances of ^{52}Cr.

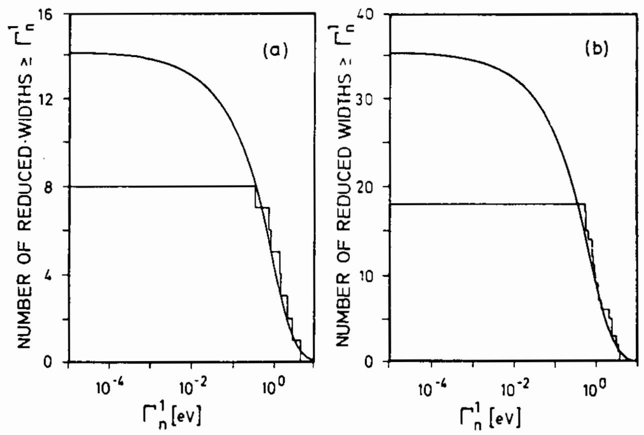


Fig.5: Histogrammes of reduced neutron widths for p-wave resonances of ^{52}Cr fitted with Porter-Thomas distributions;
a)energy range: (0-200)keV, (N = 14 ± 4)
b)energy range: (300-500)keV, (N = 35 ± 5)

of a single gap is 2%. In Fig.3 the reduced neutron width distribution of the 23 s-wave resonances is compared with a theoretical Porter-Thomas distribution and, even for such a small number of resonances, the distribution observed follows the theoretical curve.

As mentioned in the introduction, being a closed shell nucleus ^{52}Cr could exhibit some properties that deviate from the statistics. Furthermore ^{52}Cr, in contrast to the other chromium isotopes, has a multiple of four nucleons in the target nucleus (α-cluster) similar to ^{32}S and ^{28}Si, where for the first time several doorway structures with a small spreading width have been assigned as a result of discontinuities in the level spacing[10].

The interpretation of the gaps and the level distribution of s-wave resonances are discussed in a further contribution to this conference[11] The s-wave level spacing $D_0=(41.5 \pm 4.4)$keV.

p-waves. Another even stronger discontinuity in the level spacing is observed for p-wave resonances as shown in Fig.4. If the resonances up to 500keV are considered and only p-wave resonances are assigned, two regions can be distinguished where the level spacing distribution is linear, namely the intervals (0-200)keV and (300-500)keV. The ranges are separated by a clustering of p-wave resonances at 250keV. The strong increase in levels at this point can be interpreted as a threshold for additional resonances with higher hierarchy as discussed in ref.9. The level spacings in the intervals (0-200)keV and (300-500)keV have been estimated by individual fitting with a Porter-Thomas distribution (Fig.5) for the reduced widths. The results are D_1=14.7keV and D_1=5.7keV respectively.

Strength functions

s-waves. The sum of the reduced neutron widths of s-wave resonances is plotted as a function of energy in Fig.6. A linear fit of the data over the complete energy range gives the s-wave strength function $S_0=(2.85 \pm 0.25)\times10^{-4}$. That we do not observe an energy dependence, as reported in ref.2, is explained by the discrepancies mentioned where we have compared the two data sets of neutron widths. The average values for S_0 in both sets agree within 3%, but are however 30% lower than predicted by the optical model. As described in ref.2, where the

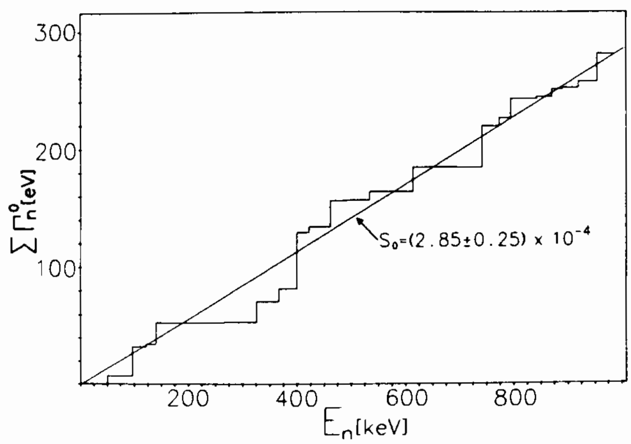


Fig.6: Sum of reduced neutron widths for twenty three s-wave resonances of ^{52}Cr vs. energy.

authors compare the strength functions of two chromium isotopes with those calculated by Müller and Rohr[12], the importance of the doorway concept for the strength function is demonstrated.

p-waves. The p-wave strength function has been obtained from Fig.7 as $S_1=(0.30 \pm 0.05)\times10^{-4}$ in the energy range below 200keV and agrees with that beyond 300keV. The sudden step at 250keV corresponds to a non-statistical effect in the strength function at this energy and is also to be seen in the plot of p-wave resonances. It is caused by the threshold effect of the fragmentation into more complicated states. Although there is a change in the level density below and beyond the threshold by about a factor of three there is no change in the strength function value.

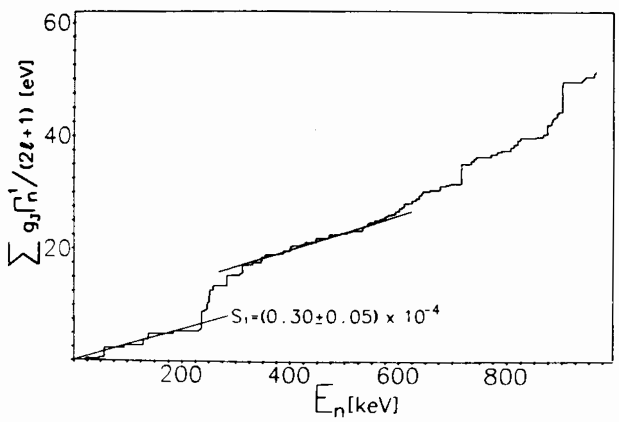


Fig.7: **Sum of reduced neutron widths for p-wave resonances of ^{52}Cr vs. energy.**

Parity dependence

The parity dependence of the level density of ^{52}Cr indicated in ref.2, i.e. the observation of 5.3 times more p-wave than s-wave levels, is based upon the assumption that, apart from three d-wave resonances, all non s-wave resonances are p-wave. However we observe a considerable number of d-waves and also expect a portion of the unassigned small resonances to be so. Therefore our determination of the p-wave level density is based upon assigned p-wave resonances only. The results show a decrease in the level spacing with $D_1=14.7$keV and $D_1=5.7$keV in the energy ranges (0-200)keV and (300-500)keV respectively. The level spacing of the low energy interval is a factor of three smaller than the observed s-wave spacing and in agreement with the level statistics. However, in the higher energy interval there are 7.8 times more p-wave resonances than s-wave resonances, indicating a local parity dependence. In the ORNL publication a parity dependence for the whole measured range has been stated.

Conclusions

For the first time level spacing discontinuities are observed experimentally. Two gaps are observed in the s-wave level distribution, where at least two resonances for each gap are missing. It has been shown that for our high resolution measurement all s-wave resonances are detected. The probability of having two such gaps has been estimated to be 0.2%, indicating a non-statistical effect.

Another even stronger discontinuity in the level spacing is observed for p-wave resonances. In the p-wave level distribution, Fig.4, three energy ranges with different level spacings may be distinguished. The level spacing decreases by a factor of 2.6 between the ranges (0-200)keV and (300-500)keV. In the intermediate region an even smaller level spacing is observed, indicating a threshold behaviour for a fragmentation to a higher hierarchy of states. The pronounced threshold behaviour may be created by a doorway structure of small spreading width. Similar effects have been observed in ^{28}Si and ^{32}S which, like ^{52}Cr, have a multiple of four nucleons in the target nucleus. This behaviour of the p-wave level spacing causes a local parity dependence, in contrast to a recent ORNL publication[2] where a parity dependence for the whole measured range has been stated. The discontinuities in the level spacing of s-wave resonances are discussed in more detail in ref.11.

The value for the s-wave strength function is 30% smaller than that predicted by the optical model and is in agreement with the doorway concept.

REFERENCES

1 G.Rohr: Z. Phys. A318, 299(1984)
2 H.M.Agrawal et al: Phys. Rev. C30, 1880(1984)
3 G.Rohr: to be published
4 F.H.Fröhner: Kernforschungszentrum Karlsruhe Report KFK-2129, (1976).
5 F.G.Auchampaugh: Report CA-5473-MS, (1974).
6 H.Beer, R.R.Spencer: Nucl.Phys.A240, 29(1975)
7 B.J.Allen, J.W.Boldeman, R.L.Macklin: Nucl. Sci. Eng. 82, 230(1982).
8 C.D.Bowman et al: An. Phys. 17, 319(1962)
9 E.M.Cornelis et al: Proc. of Int. Conf. on Nuclear Data for Science and Technology, Antwerp 135(1982)
10 G.Rohr: 6th Int. Conf. on Gamma-Ray Spectroscopy, Leuven, Belgium, to be published
11 G.Rohr: contribution to this conference
12 K.N.Müller, G.Rohr: Nucl.Phys, A164, 97(1971)