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Elastic Scattering of Protons from Chromium

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Summary. Elastic scattering of protons from chromium has been measured in the energy range 2.4–4.1 MeV. Only one of many strong resonances is attributed to an analogue state to an excited level with $J^\pi = 3/2^-$ at $E_x = 2.321$ MeV in ^{53}Cr. The Coulomb energy displacement is given as $\Delta E_c = (8.354 \pm 0.005)$ MeV.

1. Introduction

The investigation of analogue states in medium and heavy nuclei is now a well known tool in nuclear spectroscopy. It can be used to determine properties of energy levels as well as Coulomb energy differences. We have started a set of measurements, scattering protons elastically from medium-heavy nuclei. Chromium was chosen as a target nucleus in order to compare Coulomb-energy differences between the four neighbouring isotopes. Here we report results which show that only a very few of many strong scattering resonances appear to be due to analogue states.

2. Experimental Method

We used protons from a 5.5 MeV-HVEC-van-de-Graaff accelerator to bombard targets of natural and enriched chromium evaporated on carbon foils. For the excitation curves between 2.4 MeV and 4.1 MeV proton energy target thicknesses of 40 μg/cm^2 of natural chromium on carbon of 8 μg/cm^2 were used. To obtain better energy resolution limited energy regions were investigated with targets of ^{52}Cr (99.72% enriched) of 2 μg/cm^2 thickness on 5 μg/cm^2 carbon foils. The beam energy spread was about 100 eV per MeV proton energy [1]. The scattered protons were detected by standard methods. At all angles it was easy to distinguish the protons scattered on chromium from the ones scattered on carbon and oxygen contaminant.

3. Results and Discussion

Figure 1 shows the excitation curves for elastically scattered protons on natural chromium (83% ^{52}Cr) at angles which correspond to zeroes of low order Legendre polynomials except the one at 165°. It is known from (d, p)-reactions on ^{52}Cr that the low-lying states of ^{53}Cr are reached by neutrons with $l = 1$ or $l = 3$ [2]. Due to inhibition of $l = 3$ scattering by the centrifugal barrier we expect analogue states to show up as $l = 1$ resonances mainly. Inspection of the resonance shapes in Figure 1

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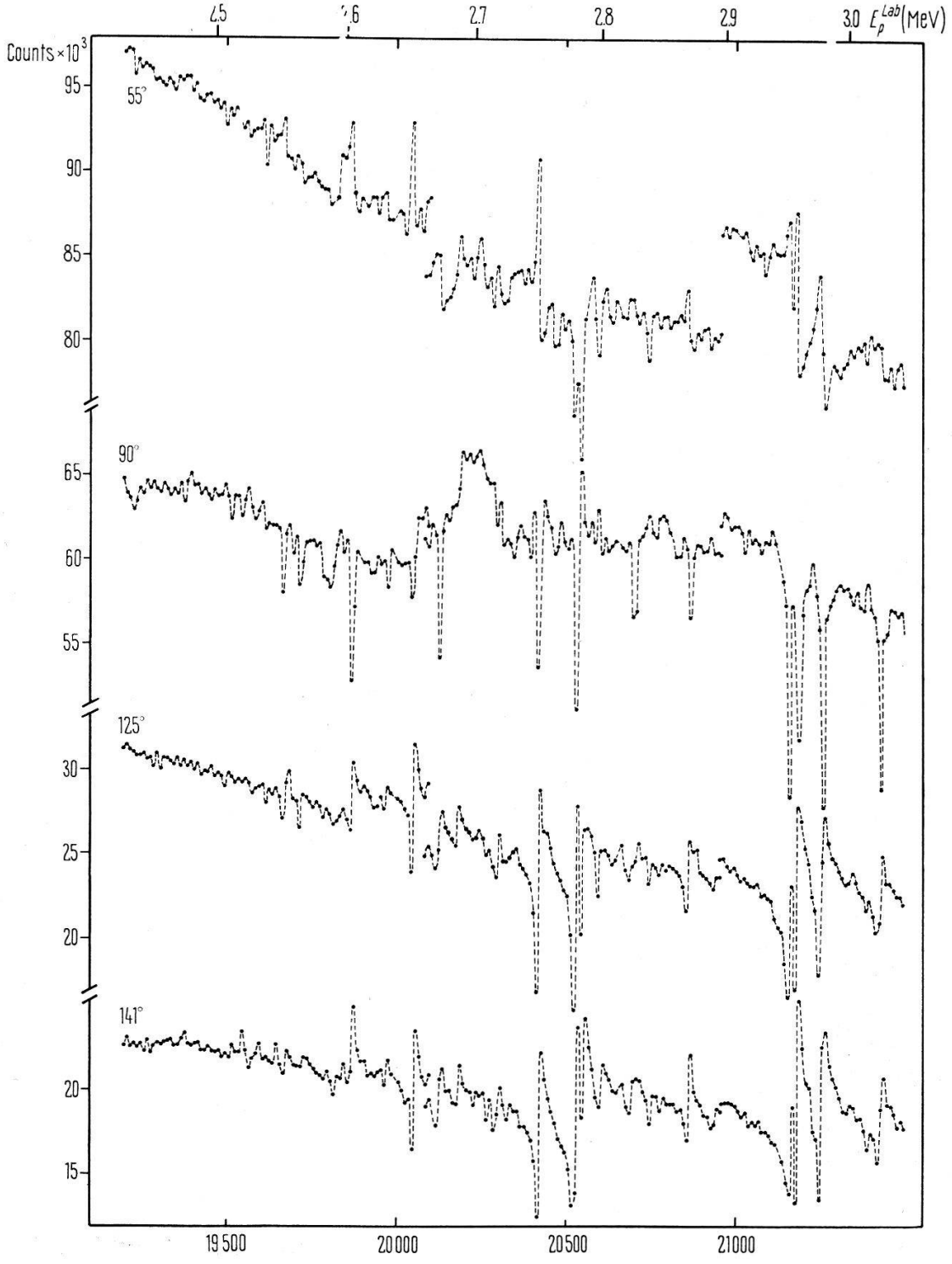
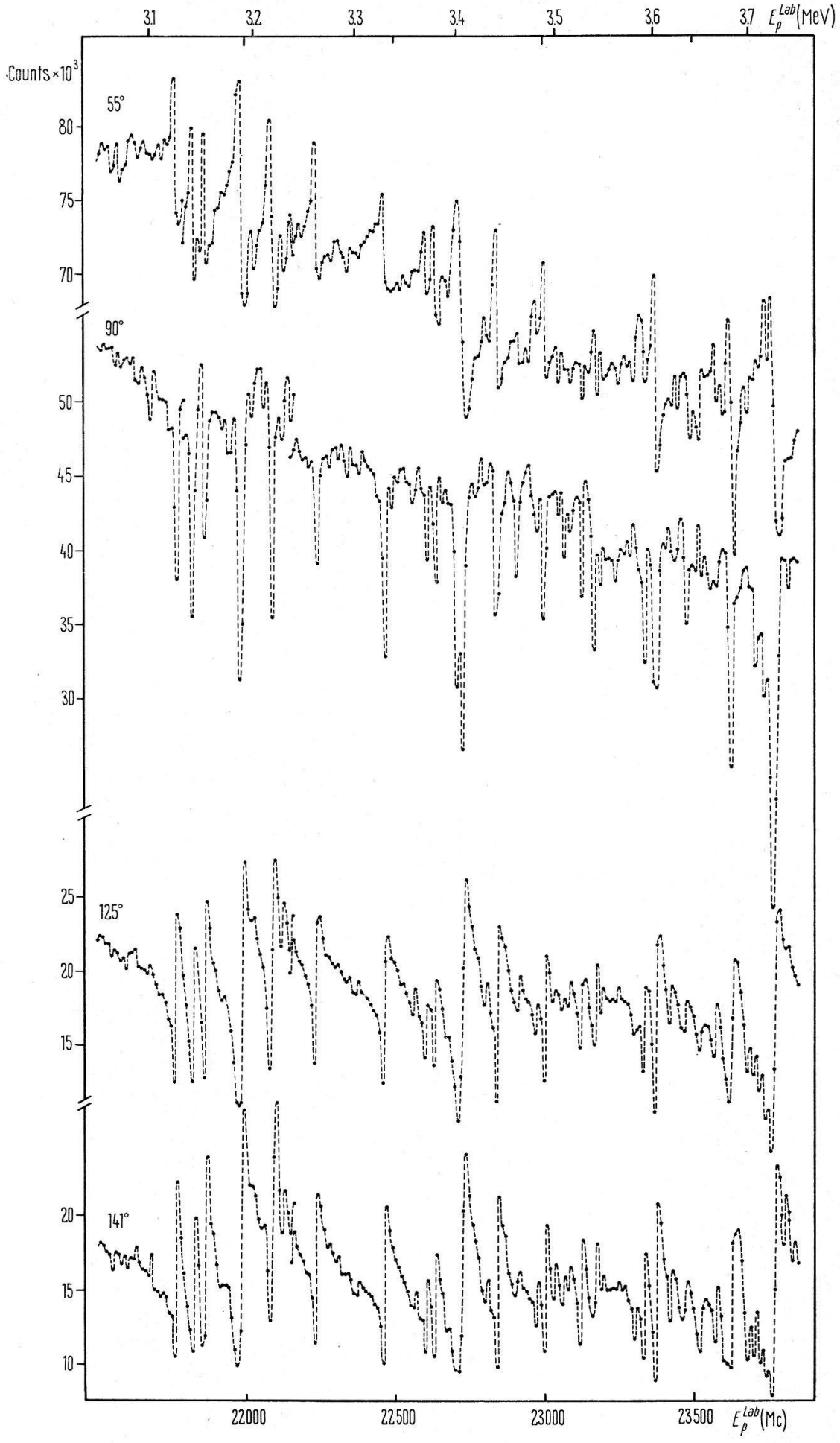
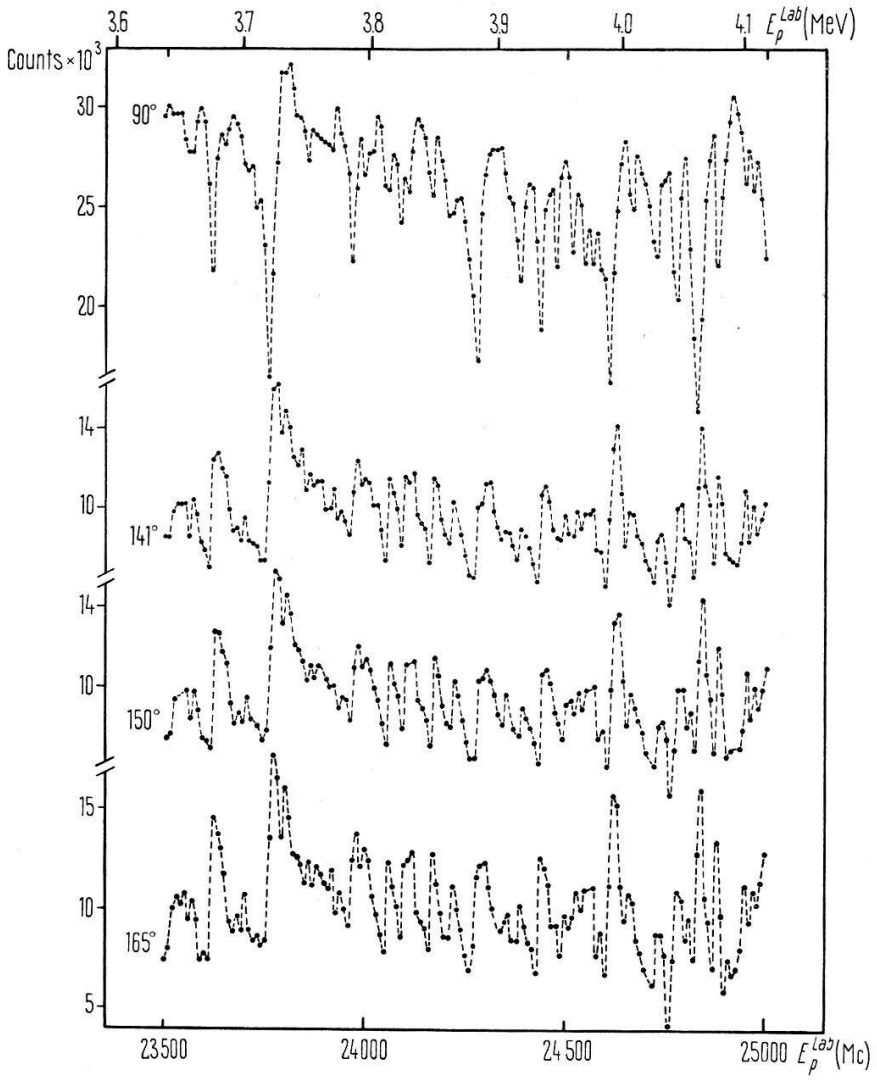


Figure 1 a), b), c)
Excitation curves for elastic scattering of protons from natural chromium (83% ^{52}Cr). Energies and angles are given in the laboratory system. The lines through the data points serve as visual aids. Different target positions in subsequent runs produced the discontinuities shown.

shows that almost all of them have a characteristic $l = 0$ pattern. An exception occurs at about $E_{lab} = 2.78$ MeV, where the 90°-excitation curve has a maximum instead of a minimum. This energy region was therefore studied with better energy resolution ($\Delta E = 400$ eV). The resulting excitation function (Fig. 2) shows a resonance with $l = 0$ and one with $l = 1$. Theoretical curves were calculated with the ANSPEC-


3.1
3.2
3.3
3.4
3.5
3.6
3.7
E_p^{Lab}(MeV)
Counts×10³
55°
80
75
70
90°
50
45
40
35
30
25
125°
20
15
141°
20
15
10
22.000
22.500
23.000
23.500
E_p^{Lab}(Mc)



program [3]. The optical parameters were taken from the work of Andrews [4], with the exception of the parameter W', the imaginary part of the potential, which depends strongly on energy. We used a lower value than given in Reference [4], $W' = 2.5$ MeV. The reduction of W' was further justified by the fact, that it reduces the resonance mixing phase ϕ_c^R [5] to about 7°, while the experimental data required an even lower value. The theoretical curves shown in Figure 2 were computed with $\phi_c^R = 0°$. The dashed lines in Figure 2 give a fit which we obtained after having varied the resonance energies and the total and partial widths. We did not measure absolute cross sections. We therefore normalized the theoretical curves to our data at off-resonance points. As only elastic scattering and radiative capture of the protons are energetically possible it is reasonable that Γ_p/Γ is equal to one. The theoretical curves in Figure 2 were obtained with $j = 3/2$ for the $l = 1$ resonance. It was not possible to get an equally good fit with $j = 1/2$. At the angles 55° and 165° the fit to the lower resonance is quite poor.

It remains to be established that the resonance at $E_{lab} = 2.783$ MeV is due to an analogue to an excited state in ^{53}Cr. A rough estimate indicates that the corresponding state in the parent nucleus ^{53}Cr should lie around $E_x = 2.4$ MeV, it must have $J^\pi = 3/2^-$ and furthermore we expect to see a state only if it has a relatively large spectroscopic factor. There is one state at $E_x = 2.321$ MeV in ^{53}Cr which fits this description

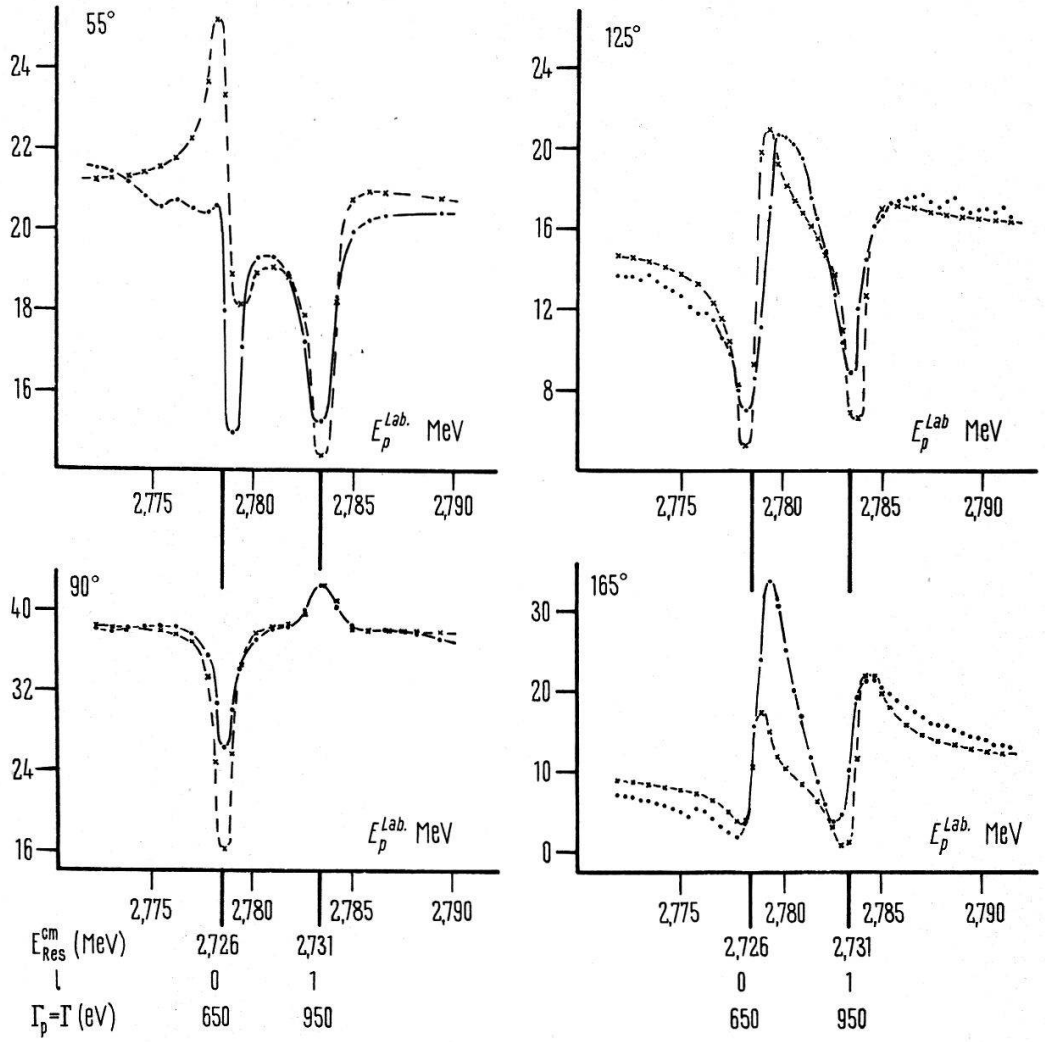


Figure 2
Results of the high resolution (400 eV) measurement in the region of the analogue to the 2.321 MeV level in ^{53}Cr.
...: experimental data points
xxx: theoretical results, calculated with the ANSPEC-program (for the parameters see text)
ordinates in arbitrary units.

[2, 8]. Taking this state to be the parent of our $l = 1$ resonant state we can calculate the Coulomb energy displacement

$$\Delta E_c = E_p^{cm} + B_n - E_x ,$$

where we take the neutron binding energy B_n in the parent nucleus and the excitation energy of the parent state from recent nuclear data tables. We obtain

$$\Delta E_c = (8.354 \pm 0.005) \text{ MeV} ,$$

which we can compare with results from (^{3}He, t)-measurements [6], where a value of $\Delta E_c = 8.350$ MeV $\pm$ 4 keV was found. In view of the fact that the latter value concerns the analogue to the ground state of ^{53}Cr, the good agreement seems accidental.

The spectroscopic factor S was calculated by the method of Thompson et al. [3, 5], again using the ANSPEC-program. We obtain a value

$$S = 0.10 .$$

From (d, p) stripping data of the corresponding state in ^{53}Cr a spectroscopic factor $S = 0.24$ was obtained [7] at a deuteron energy $E_d = 7.5$ MeV, while measurements [8] at $E_d = 10$ MeV yielded an even larger value $S = 0.31$.

The (d, p) stripping data [8] show that other $l = 1$ levels in ^{53}Cr with large spectroscopic factors occur at $E_x = 0$, $E_x = 0.57$ MeV and $E_x = 3.62$ MeV (Fig. 3). A search for analogues of these states was not successful. At the lower energy (around $E_p = 1$ MeV), this is not surprising, because the width of an analogue resonance would there be of the order of 1 eV. The search for the analogue to the 3.618 MeV level (around $E_p = 4.1$ MeV) has produced no result as yet. Interpretation of the data is difficult at these higher energies due to the very large number of closely spaced strong resonances.

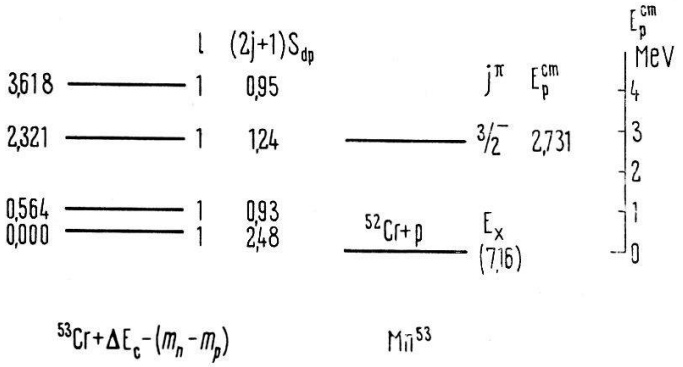


Figure 3
The isobaric pair ^{53}Cr–^{53}Mn.
The ^{53}Cr diagram is shifted by the Coulomb energy difference minus the neutron-proton mass difference and includes the $l = 1$ levels only.

It can be said in conclusion that the nucleus which we investigated does not lend itself easily to analogue state investigations. The compound level density is not high enough to produce a continuous background from which the analogue states are clearly discernible, as in the well known cases of Mo and Zr. On the other hand the number and strength of $l = 0$ resonances is such, that it is difficult both to find and to interpret the $l = 1$ analogue states. A similar behaviour was seen in the beautiful work of Browne et al. [9], who measured elastic scattering of protons on the Ni-isotopes.

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