Inelastic Scattering of Protons by Cr^{50}

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In recent years a major focus of interest at Duke has been the interpretation of data on resonance level spacings in nuclei of intermediate weight. The primary source of this data hasbbeen S wave neutron level spacings measured in the neutron total cross section. Data on 1/2+ level spacings obtained in this manner have yielded considerable information on the various factors influencing level spacings, other than the well-known dependence on excitation energy. Newson, Bowman, and others[1] have isolated the predicted effect of neutron excess and contributed information on the effect of the shell structure of the target nucleus. These factors are apparently sufficient to explain the variations in 1/2+ level spacings from nucleus to nucleus near mass number 50.

Now there is no reason either of these effects should be specific to 1/2+ levels; and it therefore becomes of interest to see if level spacings in other channels, measured by other techniques, are consistent with the picture obtained from the neutron data. For this reason we have undertaken measurements of level spacings in the resonance inelastic scattering of protons.

We consider in particular inelastic scattering by Cr^{50} to its first excited state, shown schematically in figure 1. Since we restrict ourselves to energies well below the Coulomb barrier, a proton penetrating the target nucleus is more or less bound by

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the barrier, and we expect sharp energy levels to result, leading to narrow resonances in the scattering cross section. The spin and parity of the compound state ($J\pi$) then determine the angular distribution of its decay, and the shape of this distribution can, conversely, be used to identify the resonant channel.

Because of the steep energy dependence of the Coulomb penetrability, we expect the inelastic partial width for a given resonance to be much smaller than its elastic width. If we further assume that the total width of the resonance is considerably less than the target thickness, then the peak yield of the resonance is proportional to its inelastic partial width; so that the penetration factors appropriate to the outgoing inelastic proton act to restrict the channels which are observable. Levels of spin and parity 3/2+ and 5/2+ should be the strongest since these can emit S wave inelastic protons. Levels which decay via P wave protons should be, on the average, a factor 3 weaker; those which decay via D wave protons, a factor 15 or so weaker; and so on. Levels leading to ℓ' greater than 2 we expect to be unobservably weak.

The parameters of the compound state affect bothм the angular distribution of the inelastic proton and that of the deexcitation γ ray. The p-γ distribution, as well as being more easily measured, contains more information about the spin and parity of the compound state. This is because in the p-p' distribution most of the levels emphasized by penetrabilities are isotropic, while in the p-γ distribution they have strong and characteristic anisotropies.

The outgoing channel spin s' is the coupling of the spins of the two residual particles and thus, in general, takes on two different values, each giving rise to a different angular distribution. Mixing of the two channel spin modes produces a family of possible angular distributions for each channel. However, s' must couple ℓ' and J; and thus for S wave inelastic particles only one channel spin is possible. Hence for 3/2+ and 5/2+ levels we expect a unique distribution except to the degree that D wave emission competes. This D wave competition we expect to be of the order of 5 to 7 per cent.

Experimental technique was quite straightforward. The proton beam from the Duke 3 MeV Van de Graaff was passed through our 1 meter electrostatic analyzer for energy measurement. Calibratioon of the analyzer was checked before and after the taking of the inelastic scattering data by running a $Li^7(p,n)$ threshold. Resonance energies were always reproducible within 1 keV, and the stability of the system was such that maintaining a constant energy within several hundred eV for extended periods was quite feasible. The target was a layer of 99% enriched Cr^{50} between 1.5 and 2 keV thick deposited on a 10 mil Ta backing; this was made up for us by Oak Ridge National Laboratory. γ rays were detected in a 2x2 inch NaI scintillator mounted on a turntable centered under the target spot.

Figure 2 shows a typical γ spectrum on and off resonance. Pulses were analyzed with two differential windows gated as indicated by A and B. The flat background of higher-energy γ rays was counted in B and subtracted from the A count at each energy to give the net yield of the 780 keV γ ray. The B count also served as a running monitor on any competing decay to the second excited state, which would have made interpretation of the angular distribution data considerably more difficult. No evidence of p_2 decay was seen in the energy region studied.

Figures 3 and 4 show the yield of the reaction $Cr^{50}(p,p_1,.78$ MeV) from 2.15 to 2.85 MeV at an angle of 130°. In this energy span we observe 53 resonances. Angular distributions of the γ ray yield have been studied on all but two or three of the weakest resonances.

There is a small but definite yield between resonances. Presumably this arises in part from tails of faraway resonances, in part from unobservably weak resonances in nonfavored channels, perhaps in part from a direct component. We have looked at the angular distribution of this "nonresonant" yield only sketchily. It is symmetric about 90°, or nearly so, and mildly peaked at 0°; it shows no marked energy dependence. Angular distributions on the weaker resonances have had to be corrected for this nonresonant "background" and for this purpose it has been assumed incoherent.

Figure 5 shows an angular distribution displaying the characteristic shape of a 5/2+ resonance. Note that this is taken on a quite weak resonance. Figure 6 shows another resonance angular distribution, this with the shape expected for a 3/2+ level.

Analysis of the abgular distribution data for spin and parity assignments is not complete; however, we have been able to isolate 3/2+ and 5/2+ levels fairly unambiguously. In the energy region studied we observe 10 3/2+ and 12 5/2+ levels. Accepting the peak yield as a measure of the inelastic partial width, we are able to estimate the number of resonances missed in each channel due to low yield. Incorporating this correction we arrive at level spacing values of 47 ± 13 keV for 3/2+ levels and 39 ± 10 keV for 5/2+ levels.

Correcting these numbers for excitation energy and spin dependence, we can arrive at a prediction of the S wave level spacing which should be observed in the Cr^{50} neutron cross section. For this we predict 17 ± 4 keV. Recent measurements by Farrell, Bilpuch, and Newson at Duke give a figure of 18.5 ± 2.5 keV.[2] While with data on only one target nucleus we are not in a position to make any conclusive statements about the various factors affecting level spacings, the excellent agreement between our prediction and the recent neutron experiment is quite encouraging.

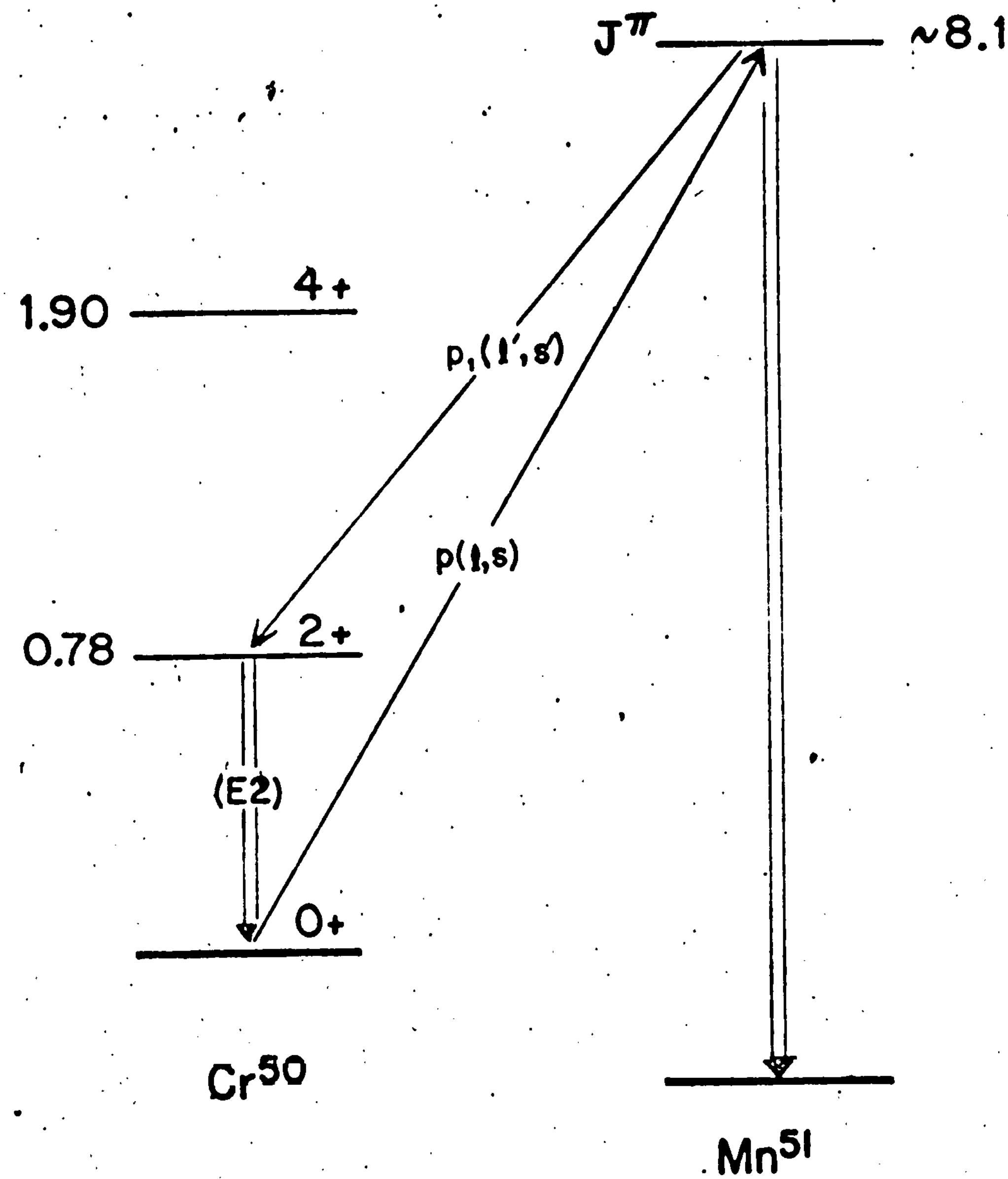
References

1. Newson, Bilpuch, Karriker, Weston, Patterson, and Bowman, Ann. Phys. 14, 365 (1961); Bowman, Bilpuch, and Newson, Ann. Phys. 17, 319 (1962).

2. J. A. Farrell, private communication.

Note

The foregoing is a draft of a contributed paper presented at the Annual Spring Meeting of the American Physical Society, April 24, 1963.



$Cr^{50}(p, p_1)Cr^{50*}$

REACTION SCHEME

Fig. 1

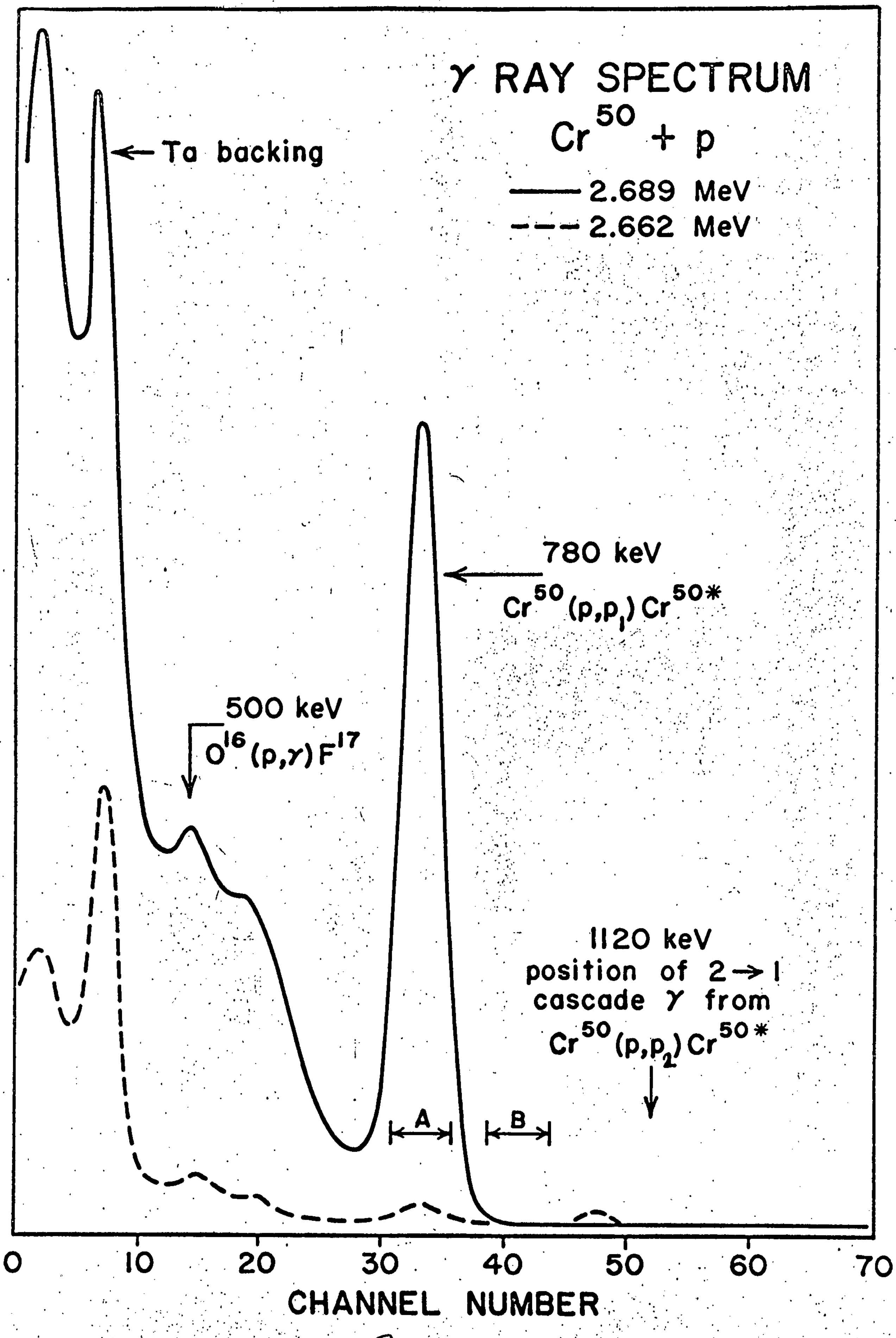
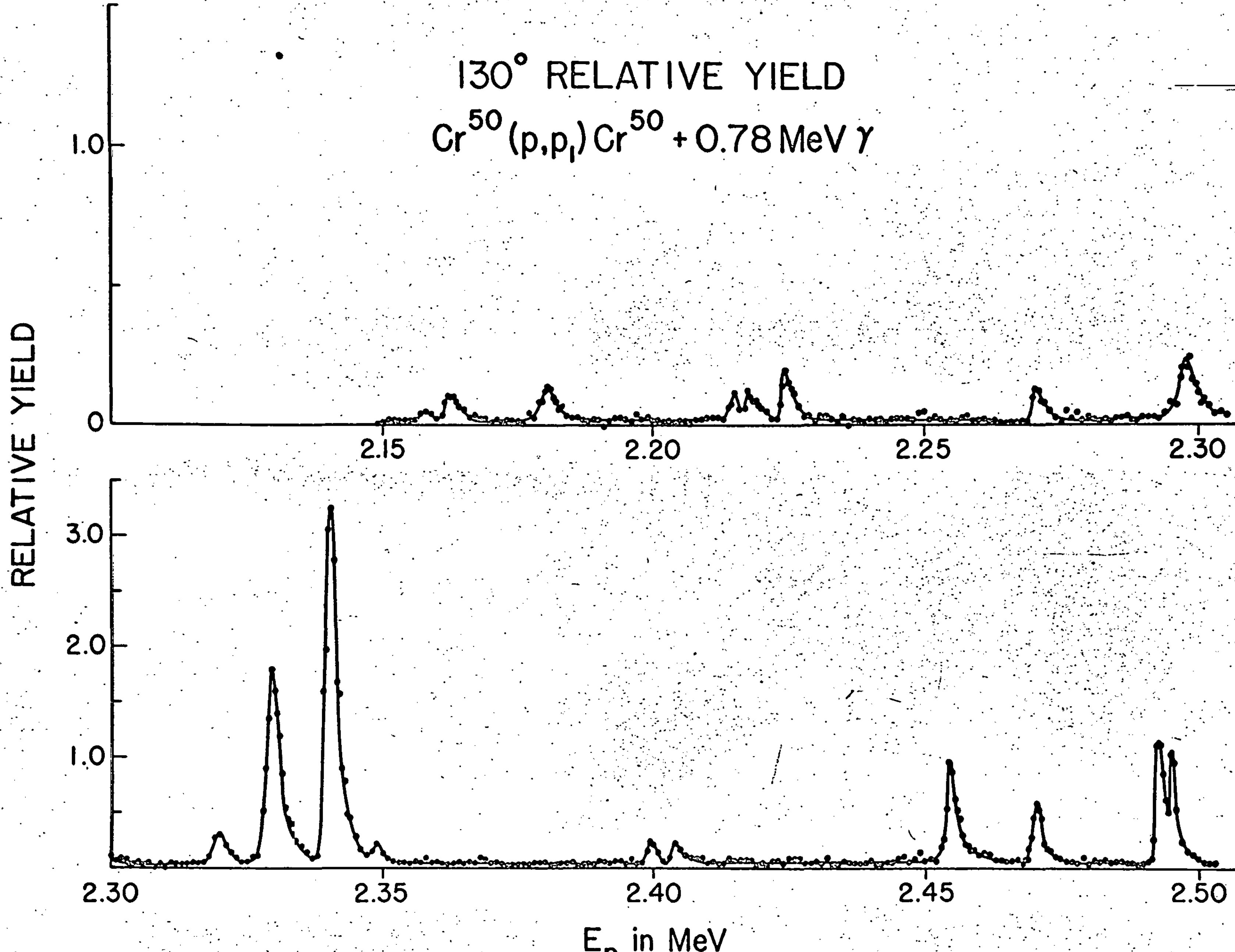
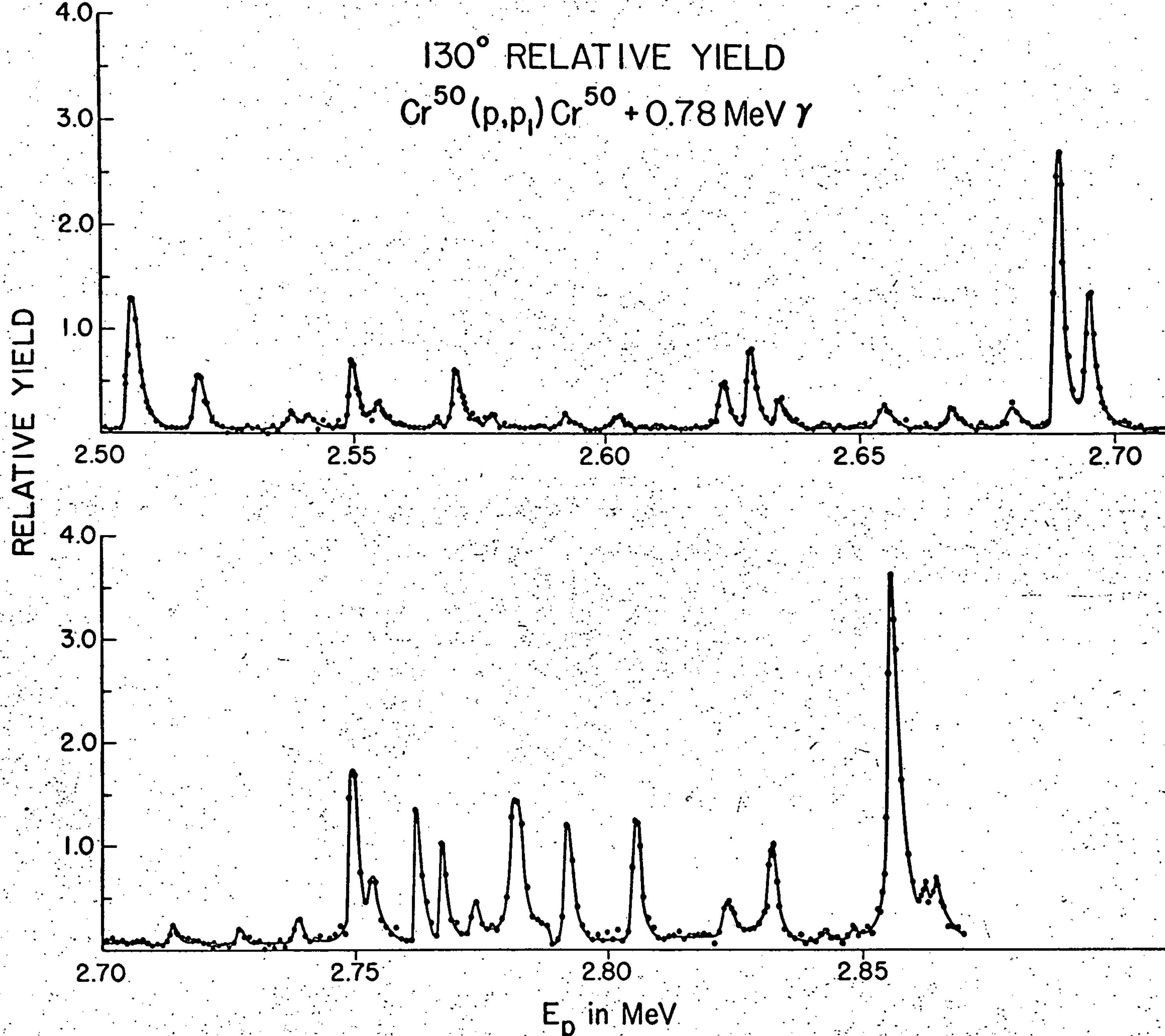

γ RAY SPECTRUM
Cr50 + p
2.689 MeV
2.662 MeV
Ta backing
780 keV
Cr50(p,p1) Cr50*
500 keV
O16(p,γ) F17
1120 keV
position of 2 → 1
cascade γ from
Cr50(p,p2) Cr50*
A
B
0
10
20
30
40
50
60
70
CHANNEL NUMBER

Fig. 2



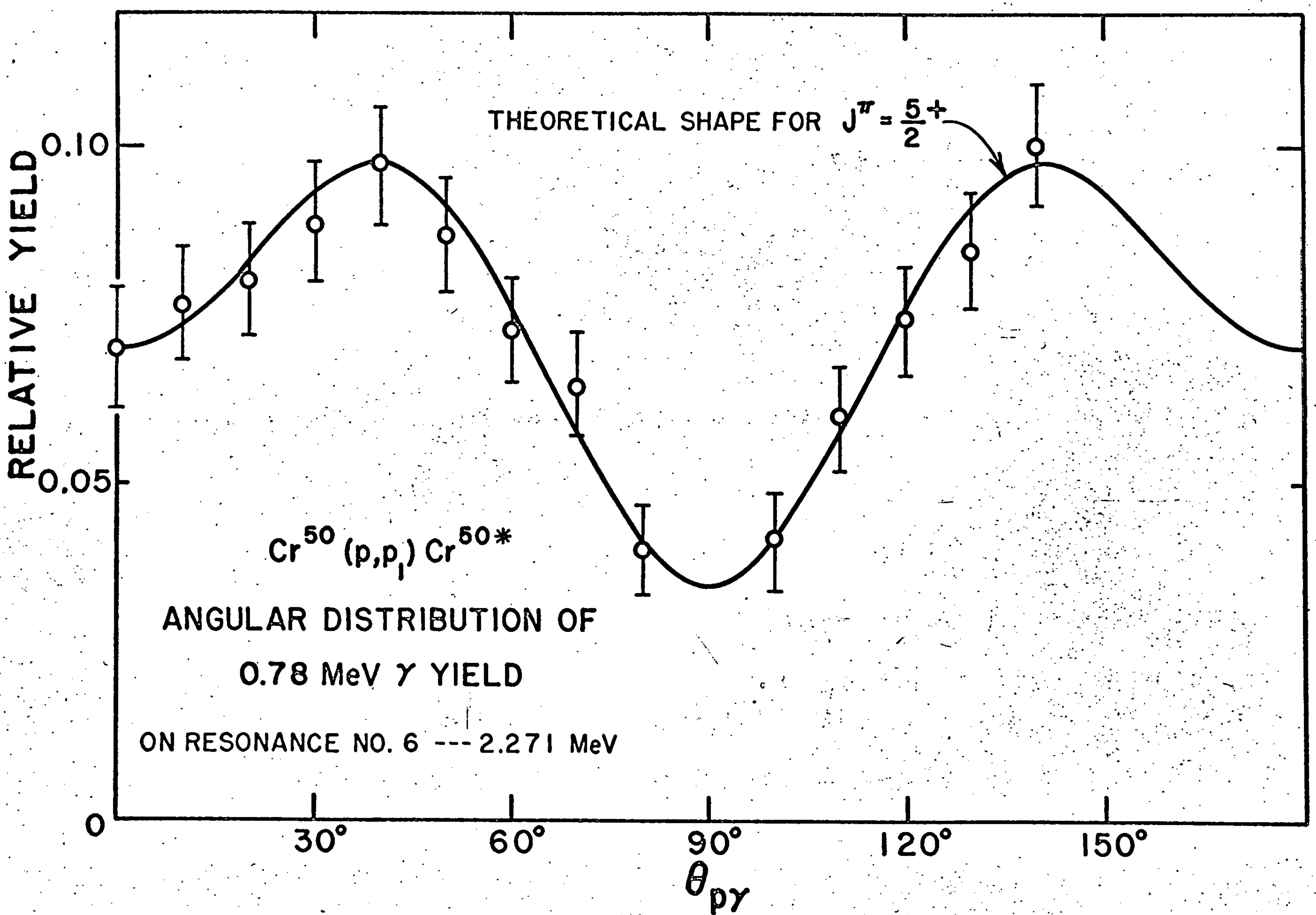
130° RELATIVE YIELD
$Cr^{50}(p,p_1)Cr^{50}$ + 0.78 MeV γ
RELATIVE YIELD
1.0
0
2.15
2.20
2.25
2.30
3.0
2.0
1.0
2.30
2.35
2.40
2.45
2.50
E_p in MeV

Fig. 3



130° RELATIVE YIELD
$Cr^{50}(p,p_1)Cr^{50}$ + 0.78 MeV γ
RELATIVE YIELD
4.0
3.0
2.0
1.0
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
E_p in MeV

Fig. 4



THEORETICAL SHAPE FOR $J^{\pi} = \frac{5}{2}^{+}$
RELATIVE YIELD
0.10
0.05
0
30°
60°
90°
120°
150°
$\theta_{p\gamma}$
$Cr^{50}(p,p_1)Cr^{50*}$
ANGULAR DISTRIBUTION OF
0.78 MeV γ YIELD
ON RESONANCE NO. 6 --- 2.271 MeV

Fig. 5

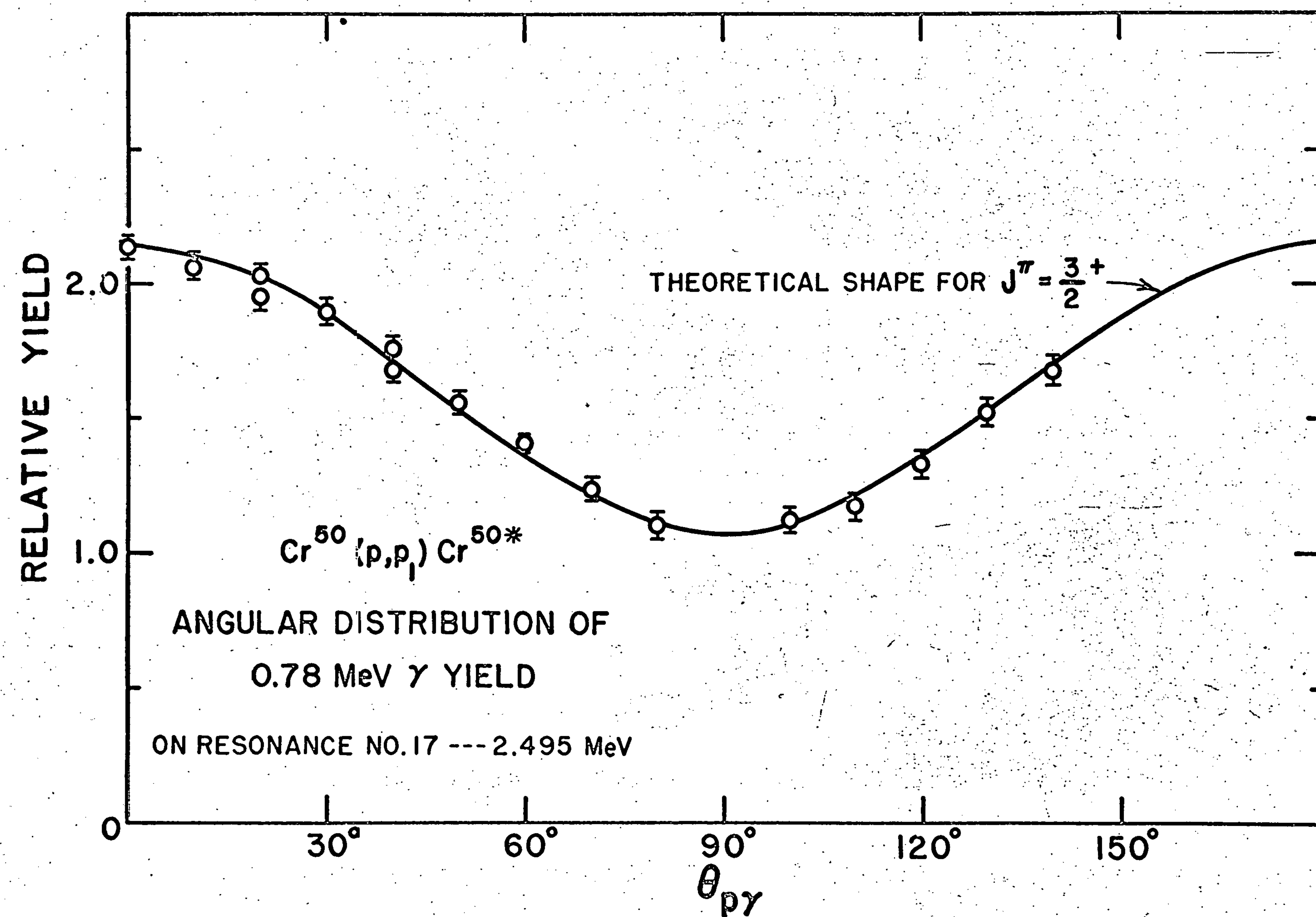

RELATIVE YIELD
2.0
1.0
0
30°
60°
90°
120°
150°
$\theta_{p\gamma}$
THEORETICAL SHAPE FOR $J^{\pi} = \frac{3}{2}^{+}$
$Cr^{50}(p,p_1)Cr^{50*}$
ANGULAR DISTRIBUTION OF
0.78 MeV γ YIELD
ON RESONANCE NO. 17 --- 2.495 MeV

Fig. 6