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The Chromium Photoneutron Cross Section*

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Abstract

A high resolution measurement of the total photoneutron cross section of chromium from threshold to 27 MeV has been obtained. The result is compared with an earlier measurement and an interpretation in terms of isospin effects is made.

Introduction

In our laboratory, a systematic study of the photoabsorption cross sections of the $1f_{7/2}$ even–even nuclei is being made. In particular, this concerns the even isotopes of calcium and the even isotones ($N = 28$) from ^{48}Ca to ^{54}Fe. The aim of this study is to elucidate the systematics of isospin splitting of the electric dipole giant resonance as predicted by Fallieros and Goulard (1970) and others (e.g. Akyuz and Fallieros 1971) and tentatively reported by Shoda *et al.* (1975). Of additional interest are the deformation effects as the shell is filled.

Experiment

The neutron yield from a 50 g target of natural chromium (^{52}Cr 83·8%) was measured in 100 keV steps from 8 to 27 MeV using bremsstrahlung radiation produced on a thin (0·05 radiation lengths) platinum flag target by electrons from the University of Melbourne 35 MeV betatron. The photoneutrons were directly detected by a 4π Halpern-type neutron detector consisting of 16 enriched $^{10}BF_3$ counters, as described by Sambell and Spicer (1973). The bremsstrahlung dose was measured with a thin transmission chamber which was calibrated against a standard NBS P2 chamber (Pruitt and Domen 1962).

To obtain data of high statistical accuracy, 22 separate yield curves were measured. All data taking was computer controlled, whereby the target was irradiated for 1 min intervals at each successive energy. This procedure minimized the effects of short-term fluctuations that could occur in the electronics or betatron energy.

The ^{52}Cr(γ, 2n) reaction threshold is at 21 MeV and the yield from this reaction is doubly enriched due to the neutron detection system. Allowance for this neutron multiplicity was made on the basis of a statistical model, the detailed procedure

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following that described by Sambell and Spicer (1973). The cross section was derived from the average of all the yield curves after corrections for detector dead times, dose drifts and neuron multiplicity. The variable bin Penfold–Leiss method as developed by Bramanis *et al.* (1972) was used, and the result is shown in Fig. 1.

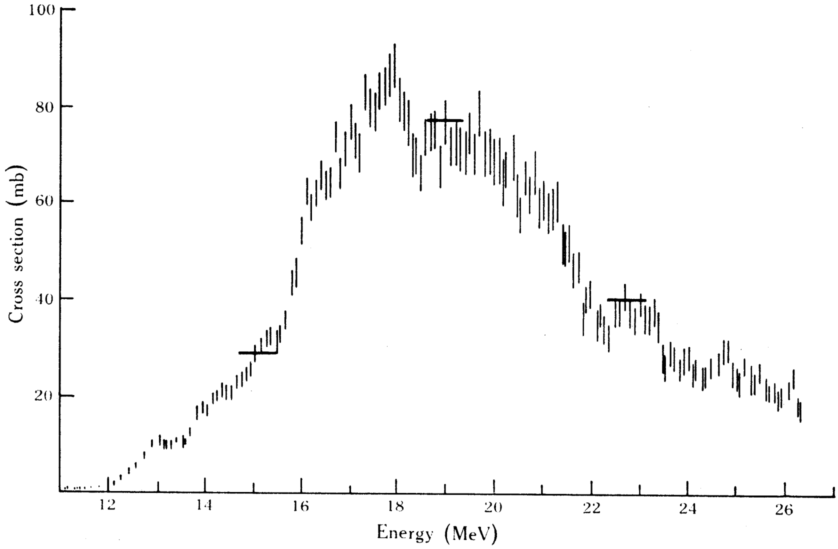

Fig. 1. Photoneutron cross section for natural chromium. The bold horizontal bars represent the analysis bin widths used.

Discussion

General

Although a natural chromium target was used in this experiment, since ^{52}Cr constitutes 83·8 % by atom, the major features of the cross section will reflect the ^{52}Cr(γ, n) reaction. The result shown in Fig. 1 exhibits considerable structure within a larger than usual giant dipole resonance (GDR) of width 5·5 MeV (FWHM). The integrated cross section from threshold to 26 MeV was obtained as 641 ± 42 mb.MeV. The only previous measurement of the cross section of chromium was made by Goryachev *et al.* (1969). They obtained a similar overall shape to that shown in Fig. 1 but with significantly more structure; however, their value for the integrated cross section of 640 ± 25 mb.MeV up to 26 MeV compares favourably with that reported here.

As pointed out by Bramanis *et al.* (1972), the structure observed in any cross section derived from a yield curve is very sensitive to the analysis procedure and special care must be taken, for example, in the choice of analysis bin widths. The present cross section was obtained from a conservative analysis, however, and therefore any evident structure is most likely real. Goryachev *et al.* (1969) did attempt to correlate, with some success, the structure they found with predictions of the dynamic collective model (Danos and Greiner 1964), but at this stage it is possibly premature to try to make such a detailed interpretation.

There are several clear resonances on the low energy side of the GDR of Fig. 1, but perhaps the most significant features are the two broad components centred at

~17·5 and ~20·5 MeV. In view of the stated interest in the effects of isospin it is tempting to identify these as the two isospin components of the GDR.

Isospin Considerations

According to Fallieros and Goulard (1970) for non-self-conjugate nuclei the GDR is split into two isospin components: one with isospin T_0, the same as the ground state (usually referred to as the $T_<$ resonance), and the other with isospin T_0+1 (the $T_>$ resonance). The separation of these two components is given by

$$\Delta E_T = 60(T_0+1)/A \qquad \text{MeV}.$$

For ^{52}Cr ($T_0 = 2$), we have $\Delta E_T = 3\cdot5$ MeV. Although this estimate is consistent with the energy difference of the two broad components of Fig. 1, it cannot in itself be considered conclusive that the splitting is due solely to isospin.

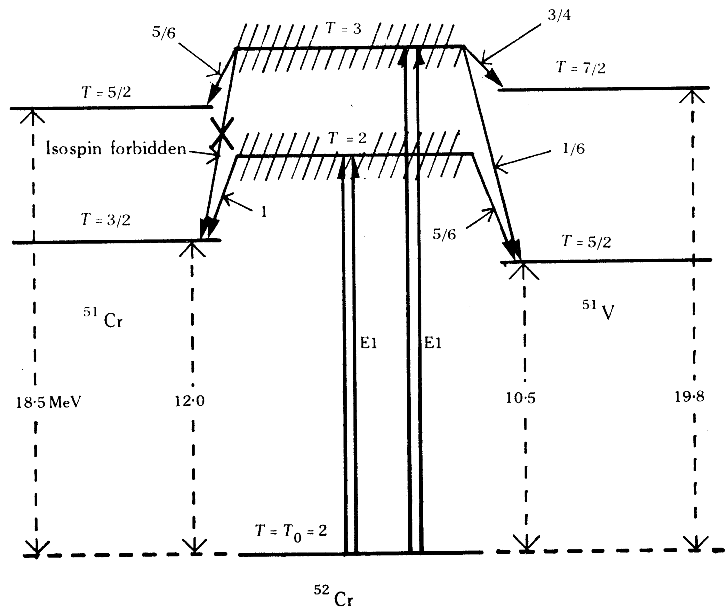

Fig. 2. Isospin coupling coefficients for the decay of the E1 GDR in ^{52}Cr. Also shown are the energies of the lowest-lying residual states of various isospin.

Photoneutron and Photoproton Branching Ratios

Further evidence may be obtained by considering both the proton and neutron decay of the two isospin components of the GDR. The nucleon decay strength from a dipole state to a residual state of a particular isospin is calculated using Clebsch–Gordon isospin coupling coefficients (Fallieros and Goulard 1970). Fig. 2 summarizes these coefficients and shows the specific values for ^{52}Cr where $T_0 = 2$. The figure also shows the energies of the photonuclear thresholds and the lowest $T_0+\frac{1}{2}$ and $T_0+\frac{3}{2}$ states in the ^{51}Cr and ^{51}V residuals.

If isospin is responsible for splitting of the GDR, three related factors should produce a large difference in the decay probabilities for neutron and proton emission from the two isospin components:

(1) the coupling coefficients shown in Fig. 2;

(2) the disallowed neutron decay from the $T_>$ GDR to the low lying residual states of ^{51}Cr;

(3) the effective inhibition of proton decay from the $T_>$ GDR to the $T_0+\frac{3}{2}$ states in ^{51}V.

Comparison of the predicted and experimental ratio R of $\sigma(\gamma, \mathrm{n})$ to $\sigma(\gamma, \mathrm{p})$ for the two isospin components should provide a good test as to whether isospin splitting does occur. Thus if the data presented here are interpreted to indicate a $T_<$ component at 17·5 MeV and a $T_>$ component at 20·5 MeV then cross section strength seen at high energies (say above 22 MeV) will represent essentially $T_>$ dipole states decaying by neutron emission. Similarly cross section strength below about 17 MeV will represent $T_<$ neutron strength. The ratio R can be estimated in these energy regions and compared with experimental data.

Table 1. Comparisons of experimental ratio of photoneutron to photoproton cross section with predicted values for different decay modes

(1) Energy region (MeV)	(2) Experiment	(3) Compound nucleus	(4) Direct plus compound nucleus	(5) No isospin
	$R = \sigma(\gamma, \mathrm{n})/\sigma(\gamma, \mathrm{p})$			
16–17	6·7±1·3	11·3	7·2	6·2
22–24	1·2±0·2	0·2	1·2	3·1

Two measurements of the ^{52}Cr(γ, p) reaction have been made. One by Ishkhanov *et al.* (1970) and a later one by Thompson *et al.* (1975). Comparison in this paper is restricted to the work of Thompson *et al.* since the reported cross section is less structured and the analysis procedure more fully available to us. However, the same conclusions are reached if a smoothed version of the cross section of Ishkhanov *et al.* is used. Table 1 summarizes the values of the ratio R determined in the two energy regions. The experimental ratio may be in error by up to 20%, but the difference (6·7 to 1·2) is still significant.

The simplest reaction mechanism that can be used to caluclate the ratio R is compound nucleus formation and decay. On this basis the GDR states decay statistically to the available residuals. By making allowance for the isospin selection rules, the number of available residual states for each mode of decay, and attenuation due to Coulomb and angular momentum effects (a value of $l = 2$ was used), the values listed in column 3 of Table 1 were calculated. Considering that this is only a rough estimate, the agreement with experiment is regarded as satisfactory.

It is now generally accepted that the decay of the GDR is at least partially by a direct or semidirect mechanism which leads predominantly to the population of the low-lying residual states. De-excitation γ-ray studies at our laboratory (Thomson *et al.* 1972) and elsewhere, together with measurements of the photoproton spectra (Bangert *et al.* 1976) and photoneutron spectra (Sherman *et al.* 1976), show that the low-lying states are more strongly populated than is predicted by statistical decay. The relative proportion of the two modes is not known and probably varies systematically throughout the periodic table. If decay of the GDR occurs entirely to the lowest few residual states, the value obtained for the ratio R is 2·8 above 22 MeV (after allowing for angular momentum attenuation of the neutrons) and 1·2 below 17 MeV. Thus introducing a proportion of direct decay will increase the number of high energy nucleons, noticeably changing the values of R. This is seen in column 4 of Table 1, which lists the ratio on the assumption that 40% of the GDR decay is to low-lying states in ^{51}V and ^{51}Cr, while the rest is statistical as for column 3. The agreement with experiment is even better than before.

Column 5 of Table 1 lists values of the ratio R calculated as for column 4 except that no allowance has been made for the isospin coupling coefficients and selection rules. In other words, these ratios are such as would be predicted if the GDR splitting were not isospin dependent. The agreement with experiment is no longer as good and the importance of isospin in the calculation is vindicated.

Conclusion

A comparison of the high resolution measurement of the Cr(γ, n) cross section reported here with published Cr(γ, p) cross sections suggests that the reported splitting of the giant dipole resonance in ^{52}Cr is consistent with predictions based on the separation of $T_>$ and $T_<$ isospin components in the dipole states.

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