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Photoneutron Cross Section of ^{54}Fe†

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Abstract

A high resolution measurement of the ^{54}Fe(γ, n) cross section is reported. This and a previously measured ^{54}Fe(γ, p) cross section are discussed in terms of the isospin splitting of the E1 giant dipole.

Introduction

The present measurement of the ^{54}Fe(γ, n) cross section is part of a program of photoneutron and photoproton cross section measurements currently being made using the 35 MeV betatron at the University of Melbourne and the electron linac at Tohoku University in Japan. The nuclei being studied are the even mass isotopes of calcium, from ^{40}Ca to ^{48}Ca, and the even mass isotones from ^{48}Ca to ^{54}Fe. This selection of nuclei may show systematic isospin effects as predicted by Fallieros and Goulard (1970) and tentatively observed by Shoda *et al.* (1975). Other systematic changes in the cross section such as splitting due to deformation as the $1f_{7/2}$ shell is filled may also be observed.

Experimental Procedure

The cross section was derived from an activation yield curve which was determined by measuring the 8·5 min β^+ residual activity of ^{53}Fe induced following the ^{54}Fe(γ, n)^{53}Fe reaction. A unique signature of the ^{53}Fe component was obtained by counting positron annihilation photons in coincidence with the 0·38 MeV de-excitation γ rays from the first excited state of ^{53}Mn populated by 38% of the β^+ decay. This technique not only removed all activity due to competing reactions, but also reduced the experimental background to a negligible level.

The activation yield curve was measured in 200 keV intervals from 12 to 28 MeV using bremsstrahlung produced in a thin (0·05 radiation length) platinum target. The activity was measured from 45 individual natural iron targets of 99·5% purity. These were in the form of cylinders 4 cm in diameter and 2 cm thick. It was necessary to use irradiation times that varied from 20 min at 12 MeV down to 1 min at 28 MeV. This time was optimized to keep dead time corrections to reasonable values, yet to provide acceptable statistical accuracy.

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The X-ray dose was measured using a thin walled transmission ionization chamber (Hicks 1972) with an inbuilt decay rate of 8·5 min, which is the same as that of the ^{53}Fe nuclei. The induced activity was counted for 20 min, starting 1 min after irradiation was completed. To check the stability of the electronic systems, standard yield points were measured at 26 MeV after every five data points. Observed variations in this standard point were used to correct for electronic drifts. Targets were recycled and used several times during the experiment, since remnant activity was negligible and no additional correction was needed.

Two complete yield curves were measured and the average curve was analysed using the Variable Bin Penfold–Leiss (VBPL) method (Bramanis *et al.* 1972), assuming an integrated (over angles) Schiff bremsstrahlung spectrum. The cross section scale was obtained by normalizing the integrated cross section from this experiment with that reported by Carver and Lokan (1957).

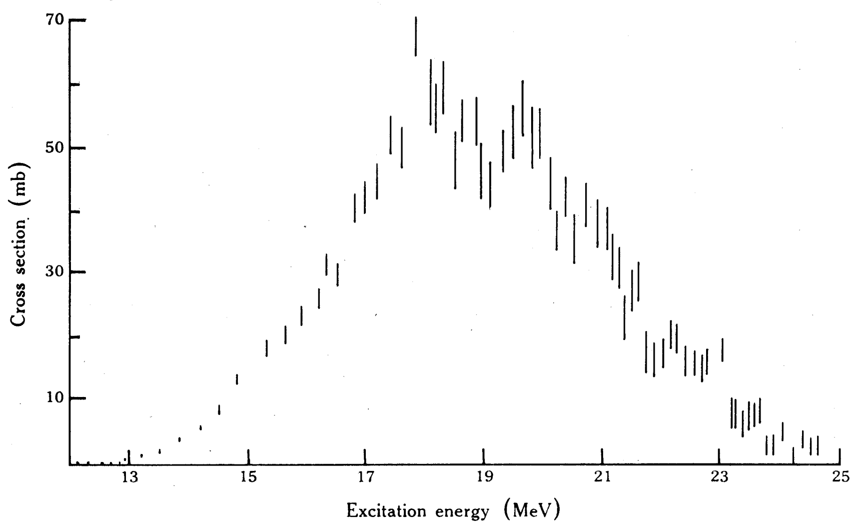

Fig. 1. ^{54}Fe(γ, n)^{53}Fe cross section obtained from the present high resolution measurement.

The cross section determined in the present experiment is shown in Fig. 1. The gross features are two large peaks centred around 17·9 and 19·8 MeV. The general shape agrees quite favourably with that obtained by Carver and Lokan (1957) and by K. Kageyama and E. Tanaka (personal communication), both of which were low resolution measurements and do not reveal the detailed structure of the present result. The recent measurement by Ratner *et al.* (1977) of the ^{54}Fe(γ, n) cross section also agrees quite well in overall shape. However, a detailed agreement is not expected since they measured only neutrons with energies greater than 0·9 MeV.

Discussion

A recent measurement of the ^{54}Fe(γ, p) cross section has been made by one of us (H.T.) and the data are shown in Fig. 4*b* below. This cross section has its major strength at 20 MeV, about 2 MeV higher than the major strength of the (ν,n) cross

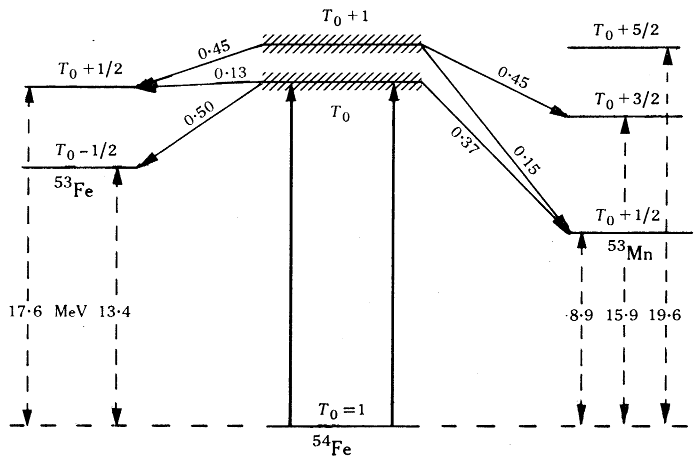

Fig. 2. Decay scheme for ^{54}Fe.

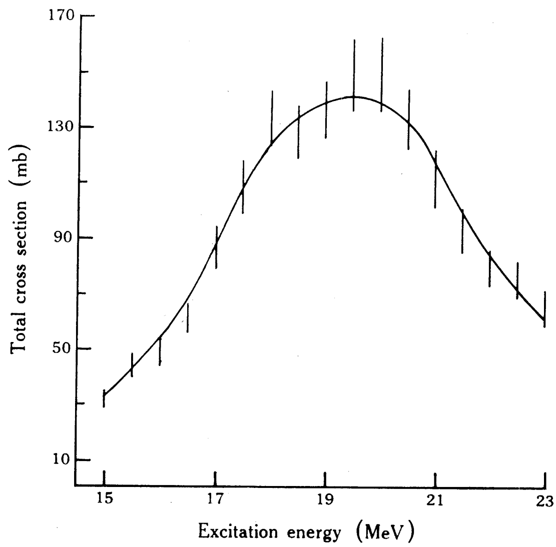

Fig. 3. Total photoabsorption cross section for ^{54}Fe. The data points are the sum of the (γ, n) and (γ, p) cross sections of Figs 1 and 4*b* and the curve is a fit of the two isospin components $T_<$ and $T_>$ defined in the text.

section measured here. This is generally consistent with the expected splitting of the giant dipole resonance due to isospin. The discussion below illustrates this consistency more quantitatively.

According to calculations by Fallieros and Goulard (1970), the giant dipole resonance in non self-conjugate nuclei will consist of two components, one with isospin T_0 (that of the ground state) and the other with isospin T_0+1. These isospin components, designated the $T_<$ and $T_>$ resonances, will be separated by an energy ΔE given by

$$\Delta E = 60(T_0+1)/A. \qquad (1)$$

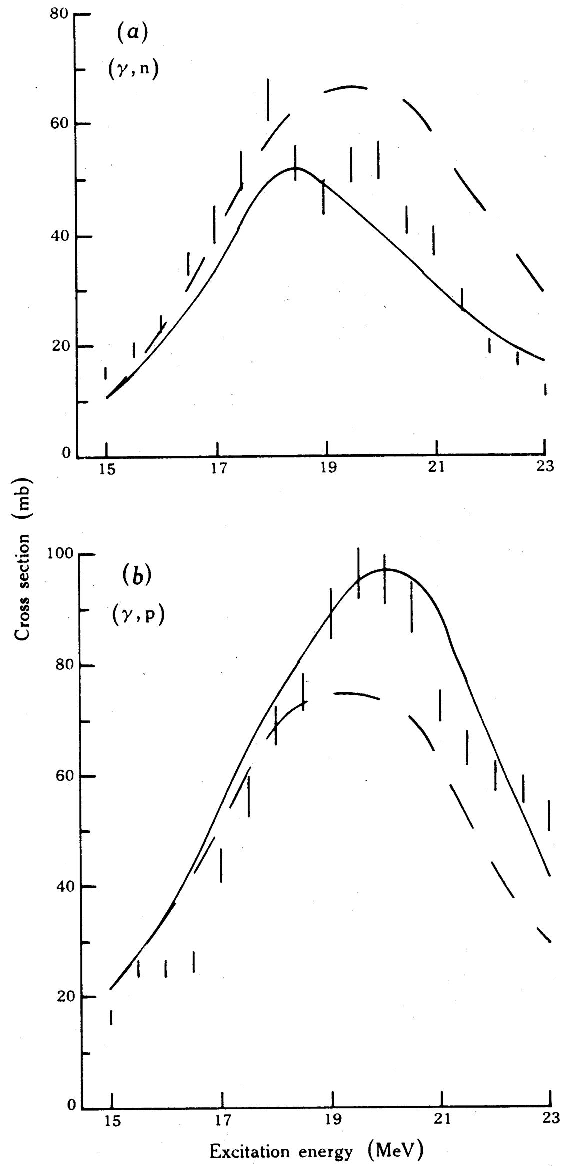

Fig. 4. Comparison of measured and calculated cross sections for (*a*) $^{54}Fe(\gamma, n)$ and (*b*) $^{54}Fe(\gamma, p)$. In each case the solid curve is the result of a calculation which includes isospin effects, while the dashed curve is obtained if isospin is ignored in the calculation.

Their relative energy-weighted integrated cross sections are

$$\frac{\int E^{-1}\sigma(T_>)\,\mathrm{d}E}{\int E^{-1}\sigma(T_<)\,\mathrm{d}E} = \frac{1}{T_0}\left(\frac{1-\frac{3}{2}T_0A^{-2/3}}{1+\frac{3}{2}A^{-2/3}}\right). \tag{2}$$

Decay of each component by neutron or proton decay is different. The coupling coefficients are shown for the case of ^{54}Fe in Fig. 2. Also included in the diagram are the relevant reaction thresholds.

Since both the (γ, p) and (γ, n) cross sections are known it is possible to test the importance of isospin in the decay of ^{54}Fe. These decay modes constitute approximately 98% of the total absorption cross section; thus their sum gives a close approximation to the total absorption cross section. The data points in Fig. 3 show the approximation to the absorption cross section obtained by summing the (γ, p) cross section of Fig. 4*b* and the (γ, n) cross section of Fig. 1. The solid line through the points in Fig. 3 is the sum of two Lorentzian curves representing the $T_<$ and $T_>$ components. The widths and heights of these curves were adjusted to give the best least squares fit to the data. In fact the best fit was obtained when the widths of the two Lorentzians were identical. Also the requirements of equations (1) and (2) were explicitly fulfilled in the fitting procedure. By postulating a decay mechanism, as detailed below, the individual (γ, p) and (γ, n) cross sections can be calculated from the fitted total absorption cross section.

It has been assumed that the decay is essentially statistical with the exception of 10% which is taken to decay by a semi-direct process to low lying residual states. This direct fraction is included to be consistent with the recently published ^{54}Fe(γ, n) data of Ratner *et al.* (1977), which show a high energy neutron component consistent with a direct decay mechanism for about 10% of the neutrons. The calculation of the decay of the $T_<$ and $T_>$ components takes into account the isospin coupling coefficients and thresholds shown in Fig. 2. Allowance for Coulomb inhibition is included with a barrier height of 6·2 MeV. The residual level density was assumed to be given by the back-shifted Fermi gas model (Dilg *et al.* 1973) which gives realistic results in this mass region.

Figs 4*a* and 4*b* show the measured and calculated (γ, n) and (γ, p) cross sections respectively. The solid curves in the figures are the results of the calculation described above. The agreement with experiment is good. Of particular importance is the dashed curve in each figure, which shows the cross section calculated on the same basis except that the effect of isospin in the decay process has been ingored. It is quite clear that agreement between experiment and theory is not possible unless isospin is taken into account.

From the above results we can conclude that the present high resolution measurement of the ^{54}Fe(γ, n) cross section, when taken in conjunction with an earlier measurement of the ^{54}Fe(γ, p) cross section, provides evidence to confirm the predictions of Fallieros and Goulard (1970) regarding splitting of the giant dipole resonance due to isospin.

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