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Angular Correlation Measurements in ^{57}Fe

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Abstract

The results of two γ–γ correlation measurements following the thermal capture of neutrons in ^{57}Fe are presented. The spin of the $1\cdot725$ MeV state is found to be $3/2^-$ and that of the $1\cdot627$ MeV state to be $3/2^-(5/2^-)$. The mixing ratios for the decay of the two states have been calculated.

Introduction

The spins of the energy levels of ^{57}Fe below 1 MeV are well known (Rapport 1970) but above this energy there are only a few levels which have been assigned a unique value. Most of the proposed spin assignments above 1 MeV have been obtained from the angular distributions of protons from the ^{56}Fe(d, p)^{57}Fe reaction (Cohen *et al.* 1962; Bochin *et al.* 1964; Sperduto and Beuchner 1964; Sen Gupta and Hannan 1967; Rapport 1970), which normally give two possible values. There are two states in ^{57}Fe at $1\cdot627$ and $1\cdot725$ MeV which are strongly populated in the ^{56}Fe(n(thermal), γ)^{57}Fe reaction and decay predominantly to the first excited state (14 keV) and ground state respectively. These states are ideal for γ–γ correlation studies between the initial γ-rays originating from the $1/2^+$ capture state at $7\cdot645$ MeV and the secondary γ-rays feeding the $1/2^-$ ground state ($E_\gamma = 1\cdot725$ MeV) or the $3/2^-$ first excited state ($E_\gamma = 1\cdot613$ MeV).

The spins of the $1\cdot627$ and $1\cdot725$ MeV states have been obtained previously by two different methods. The measurements of the proton angular distributions in the ^{56}Fe(d, p)^{57}Fe reaction are consistent with the value of $l = 1$ for the captured neutron for both levels (Cohen *et al.* 1962; Bochin *et al.* 1964; Sperduto and Beuchner 1964; Sen Gupta and Hannan 1967), and these results limit the spins of the levels to $1/2^-$ or $3/2^-$. The other method used by Kopecky and Warming (1969) was to measure the circular polarization of the γ-rays following the capture of polarized thermal neutrons. Their results indicated that the $1\cdot627$ MeV state was $3/2^-$ with a small possibility of being $5/2^-$, whilst the $1\cdot725$ MeV state was either $3/2^-$ or $5/2^-$ with a preference for $3/2^-$. The overall experimental evidence supports both states as being $3/2^-$, but since none of the previous experiments have given a unique result it was decided to measure γ–γ angular correlations.

Experimental Procedure and Results

The reaction ^{56}Fe(n, γ)^{57}Fe was studied using a beam of thermal neutrons (10^6 cm^{-2} s^{-1}) from the Australian Atomic Energy Commission reactor HIFAR. The target was a cylinder of 10 g of natural iron. The directional correlations of the two γ-ray cascades:

Cascade 1	7645 (6018) 1627 (1613) 14 keV
Cascade 2	7645 (5920) 1725 (1725) 0 keV

were measured in two separate runs. In each run the primary γ-ray was detected by a coaxial Ge(Li) detector of 10 cm^3 active volume, while three low energy spectra coincident with the primary transition were measured simultaneously by three $7\cdot6\times7\cdot6$ cm NaI(Tl) detectors which were located at angles of 90°, 135° and 155° relative to the Ge(Li) detector. The measured coincidence intensity as a function of angle was fitted with a series of Legendre polynomials of the form

$$W(\alpha) = a_0 + a_2 \mathrm{P}_2(\cos\alpha) + a_4 \mathrm{P}_4(\cos\alpha).$$

After normalization for $a_0 = 1$ and correction for solid angle effects of the NaI(Tl) detectors (Yates 1965) the following correlation coefficients were obtained:

Cascade 1	$A_{22} = +0\cdot06\pm0\cdot03$,	$A_{44} = 0\cdot024\pm0\cdot026$
Cascade 2	$A_{22} = -0\cdot12\pm0\cdot04$,	$A_{44} = 0\cdot01\ \pm0\cdot04$

The corrections for the solid angle effects of the Ge(Li) detector and the target turned out to be insignificant. The errors quoted above correspond to plus or minus one standard deviation of the measured coincidence intensities. The resolving time of the system (2τ) was 27 ns and the true-to-random ratio was better than 50 : 1. A detailed description of the apparatus and data evaluation procedure will be given elsewhere (Taylor and Hille, to be published).

Discussion and Conclusions

1·627 MeV state. This is the intermediate state in the 6·018–1·613 MeV γ–γ cascade and the intensity of the primary γ–ray rules out $J \geqslant 7/2$. A spin of 1/2 is also excluded by the significant anisotropy of the correlation. An assignment of $3/2^-$ gives the sequence $1/2^+$(El)$3/2^-$(Ml, E2)$3/2^-$, whose correlation function agrees with the experimental data for a mixing ratio between -25 and -8 or between $-0\cdot4$ and $-0\cdot3$. A fit of the experimental data is also possible for the sequence $1/2^+$ (M2, E3)$5/2^-$(Ml, E2)$3/2^-$ with a range of mixing ratios for both transitions, but no fit is possible when the parity of the intermediate state is assumed positive, i.e. if the sequence is assumed to be $1/2^+$(E2)$5/2^+$(El)$3/2^-$. Although the directional correlation results allow the assignment of both $3/2^-$ and $5/2^-$ to the 1·627 MeV state, other evidence indicates that $3/2^-$ is the correct spin and parity: The (d, p) results show an $l_n = 1$ stripping pattern for this state, thus allowing $1/2^-$ or $3/2^-$, and the relative intensity of the primary γ-ray indicates an electric dipole transition, thus also allowing $1/2^-$ or $3/2^-$ with the capture state being $1/2^+$.

1·725 MeV state. This is the intermediate state in the 5·920–1·725 MeV γ–γ cascade and again the intensity of the primary γ-ray rules out $J \geqslant 7/2$. A spin of 1/2 or 5/2 is not consistent with the data. The assignment of $3/2^-$ gives the sequence $1/2^+$(El)$3/2^-$(Ml, E2)$1/2^-$, and a fit of its correlation function to the experimental data yields a mixing ratio of between -10 and $-5\cdot5$ or between $0\cdot35$ and $0\cdot45$.

The two levels at 1·627 and 1·725 MeV in ^{57}Fe are interesting because they are both strongly populated following thermal neutron capture and the experimental evidence clearly indicates that each is a $3/2^-$ state yet one decays to the ground state ($1/2^-$) whilst the other decays to the first excited state ($3/2^-$) (see Fig. 1). Groshev and Demidov (1967) have given an explanation of the decay of these two states in terms of shell model wavefunctions. ^{57}Fe is two protons short of filling the $1f_{7/2}$

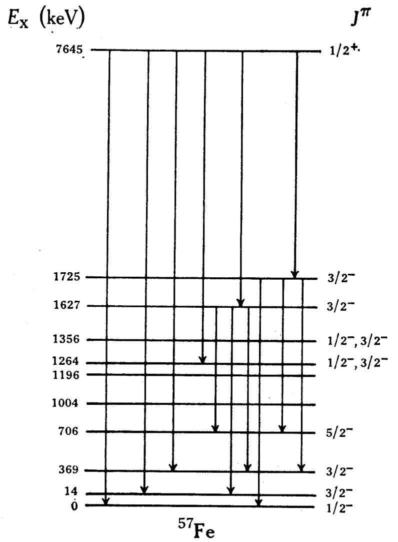

Fig. 1. Partial decay scheme of ^{57}Fe following thermal neutron capture in ^{56}Fe. Only secondary γ-rays from the 1627 and 1725 keV levels are shown.

shell and has three neutrons outside the $1f_{7/2}$ shell. The next three neutrons levels are $2p_{3/2}$, $1f_{5/2}$ and $2p_{1/2}$. The wavefunctions for the ground state ($1/2^-$) and first excited state (14 keV, $3/2^-$) given by Hamanato and Arimo (1962) are respectively

$$\pi\big(f_{7/2}^{-2}(0)\big)_0\,\nu\big(p_{3/2}^2(0)\,p_{1/2}^1\big)_{1/2}+\pi\big(f_{7/2}^{-2}(2)\big)_2\,\nu\big(p_{3/2}^2(0)\,f_{5/2}^1\big)_{5/2}$$

and

$$\pi\big(f_{7/2}^{-2}(0)\big)_0\,\nu\big(p_{3/2}^2(0)\,p_{3/2}^1\big)_{3/2}+\pi\big(f_{7/2}^{-2}(2)\big)_2\,\nu\big(p_{3/2}^2(0)\,p_{3/2}^1\big)_{3/2}.$$

If one now postulates that $\pi\big(f_{7/2}^{-2}(2)\big)_2\,\nu\big(p_{3/2}^2(0)\,p_{1/2}^1\big)_{1/2}$ is the wavefunction for the 1·627 MeV state then this state can decay to the 14 keV state but is l-forbidden from decaying to the ground state, since a neutron must then go from a $p_{1/2}$ to an $f_{5/2}$ state. If the 1·725 MeV state has a wavefunction $\pi\big(f_{7/2}^{-2}(2)\big)_2\,\nu\big(p_{3/2}^2(0)\,f_{5/2}^1\big)_{5/2}$, the state can decay to the ground state but is l-forbidden from decaying to the first excited state, as a neutron transition from an $f_{5/2}$ to a $p_{3/2}$ state is involved. If one further assumes that the capture state wavefunction contains the configuration $\pi\big(f_{7/2}^{-2}(2)\big)_2\,\nu\big(p_{3/2}^2(0)\,d_{3/2}^1\big)_{3/2}$ then this state will feed both the 1·627 and 1·725 MeV states by an El transition.

The above shell model picture of the low lying states in ^{57}Fe is also consistent with the measured multipole mixing ratios δ found in the present work. In each case two results were obtained, one large and one small. For both the decay of the 1·627 and 1·725 MeV states the smaller measured values of δ are acceptable for the proposed shell model picture, especially if a hindrance factor is included because only one component of the ground state and 14 MeV state is available for 'allowed-l' M1 transitions. The amount of hindrance will depend on the ratio of the two components in the two states. The larger values of δ cannot be explained in the terms of the proposed wavefunctions, and a more conclusive decision on the mixing ratios would require more detailed knowledge of the wavefunctions of all states involved.

The experimental evidence then clearly supports an assignment of $3/2^-$ to both the $1 \cdot 627$ and $1 \cdot 725$ MeV states. The population and decay modes are consistent with the proposed shell model picture of these states.

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