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The forbidden beta transition $\frac{1}{2}^+ \rightarrow \frac{3}{2}^-$ in ^{99}Mo

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Abstract. The angular correlation of the $\frac{1}{2}^+ \xrightarrow{\beta} \frac{3}{2}^- \xrightarrow{\gamma} \frac{1}{2}^-$ cascade in ^{99}Mo decay was studied with a fast–slow scintillation spectrometer in the beta energy region 450–700 kev. A small negative beta–gamma anisotropy is observed and the resulting angular correlation function $\epsilon(W)$ is found to lie in between $-0{\cdot}023$ and $-0{\cdot}034$ with an uncertainty of about 25%. It is concluded that the results are in accordance with the ξ approximation applicable to certain non-unique first-forbidden beta transitions.

1. Introduction

The decay scheme of ^{99}Mo is fairly well established (Dzhelepov and Peker 1961, Cretzu and Hohmuth 1965, Crowther and Eldridge 1966) and is shown in figure 1. The interesting feature of the decay scheme is the beta transition $\frac{1}{2}^+$–$\frac{3}{2}^-$ with an end point energy 880 kev and a large ln ft value, 8·5. Non-unique first-forbidden beta transitions having large ln ft values often show a deviation from the ξ or Coulombian ($\xi = \alpha z/2\rho$, where α is the fine-structure constant, z is the charge number of the daughter nucleus and ρ is the nuclear radius) approximation (Kotani and Ross 1958, 1959, Kotani 1959), thus exhibiting a non-statistical spectral shape and a large beta–gamma anisotropy. However, there are cases, for instance the first-forbidden beta decay in ^{111}Ag (Hamilton *et al.* 1960), which

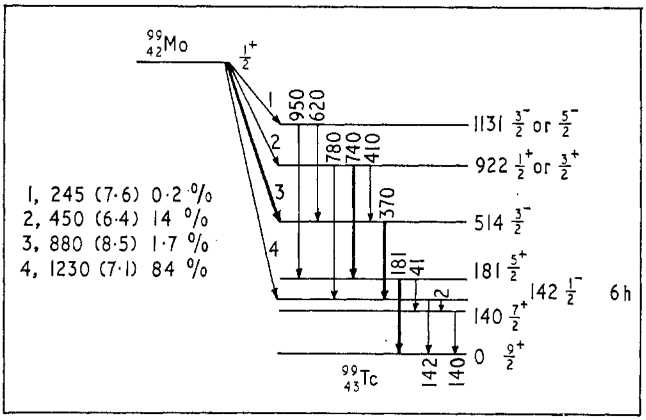

Figure 1. The decay scheme of ^{99}Mo.

show a non-statistical shape and a small beta–gamma anisotropy and vice versa. This situation arises only when some strange combinations of matrix elements govern a beta transition. The shape of the present 880 kev beta transition was found to be statistical from a Fermi–Curie plot analysis due to Cretzu and Hohmuth 1966. Very recently, Nagarajan (1968, unpublished) has undertaken shape-factor measurements on the 880 kev beta transitions in ^{99}Mo, and has found a nearly energy-independent shape for this transition. The beta–gamma anisotropy is an important parameter in the analysis of beta transitions. A combination of the several experimental observables such as the shape factor and the beta–gamma anisotropy will throw light on the nature of a beta transition. The present work concerns a systematic measurement of the energy dependence of the angular correlation for the $\frac{1}{2}^+(\beta)\frac{3}{2}^-(\gamma)\frac{1}{2}^-$ decay in ^{99}Mo. The data are analysed and discussed for the validity of the ξ approximation.

2. Experimental details

For undertaking beta–gamma directional correlation studies in these laboratories a fast–slow scintillation spectrometer was built and the characteristics of the system were given in earlier papers (Rao *et al.* 1965, 1966). The experimental tests for the intrinsic asymmetry of the correlation set-up, experimental procedure for the collection of data, the treatment of data and the various corrections were fully described in these references. The intrinsic asymmetry of the set-up was measured by undertaking the standard beta–gamma and gamma–gamma correlation experiments in ^{60}Co, separately.

The observed beta–gamma angular correlation function for the $5^+ \xrightarrow[0\cdot312\ \text{MeV}]{\beta} 4^+ \xrightarrow[1\cdot17\ \text{MeV}]{\gamma} 2^+$ cascade in ^{60}Co after applying all the corrections is obtained as

$$W_{\beta-\gamma}(\theta) = 1-(0\cdot0043 \pm 0\cdot005)P_2(\cos\theta)+(0\cdot0044 \pm 0\cdot008)P_4(\cos\theta).$$

This function represents an isotropic distribution within experimental errors, and is consistent with the allowed nature of the 0·312 MeV beta transition.

The observed correlation function for the $4^+ \xrightarrow{0\cdot17} 2^+ \xrightarrow{1\cdot33} 0^+$ cascade in ^{60}Ni after applying all the necessary corrections is found to be

$$W_{\gamma-\gamma}(\theta) = 1+(0\cdot101 \pm 0\cdot002)P_2(\cos\theta)+(0\cdot01 \pm 0\cdot004)P_4(\cos\theta).$$

This function is consistent with the theoretical one for a 4^+–2^+–0^+ spin sequence, and the values of the correlation coefficients ϵ_2 and ϵ_4 are in good agreement with the earlier measurements. Thus, one can see from these tests the non-existence of the intrinsic asymmetry of the present set-up and its suitability for undertaking angular correlation studies.

3. Source

Several samples of ^{99}Mo were obtained from the Bhabha Atomic Research Centre, Bombay. It was produced by the fission of uranium nuclei in the reactor. The ^{99}Mo fraction was separated from the fission fragments by alumina-gel chromotography. The carrier-free ^{99}Mo was finally obtained as ammonium molybdate in ammonium hydroxide solution. The ^{99}Mo source for carrying out the angular correlation measurements was prepared by allowing a drop of ^{99}Mo to evaporate to dryness on a Mylar foil of thickness 0·6 mg cm^{-2}. A drop of insulin aided uniform spreading of the source.

4. Results

The singles gamma spectrum as recorded in the corresponding gamma channel is shown in figure 2. The 370 kev gamma photopeak was accepted with a 70 kev window in both integral and differential correlation experiments. The coincidence spectrometer was operated at a fast coincidence resolution of 20 ns throughout the experiment.

4.1. *Integral correlation*

The beta channel was operated in the integral mode and beta particles of energy equal to and above 450 kev were accepted so as to eliminate interference effects from other cascades. The beta–gamma coincidences were collected only at three angles 90°, 135° and 180°, in view of the short half-life (67 h) of ^{99}Mo, so as to pool up a large number of counts at each angle and minimize the statistical uncertainties. The observed anisotropy was small and the analysis due to White (1963) was made to obtain the angular correlation function in its final form as given below

$$W_{\beta-\gamma}(\theta) = 1+(-0\cdot020 \pm 0\cdot007)P_2(\cos\theta)+(-0\cdot005 \pm 0\cdot005)P_4(\cos\theta).$$

The value of ϵ_4 is thus zero within experimental error, suggesting the first-forbidden nature of the 880 kev beta transition in ^{99}Mo. For the present beta–gamma cascade, one can thus take the angular correlation function in the form

$$W_{\beta-\gamma}(\theta) = 1+\epsilon P_2(\cos\theta)$$

writing ϵ for ϵ_2 and dropping the ϵ_4 term.

4.2. *Differential correlation*

It would suffice if one measured the coincidences at two angles for the determination of ϵ as a function of beta energy. The coincidence data were recorded employing a ten-channel analyser with a 50 kev window, at 90° and 180° and at six beta energies in the range 450–700 kev. The gamma–gamma background was negligible while the chance rate varied between 5 and 10%. The usual corrections were applied to the observed coincidences and the anisotropy values were estimated at each beta energy using the relationship $A(W) = (W_{180}-W_{90})/W_{90}$ where W_{180} and W_{90} are the normalized and corrected coincidences at 180° and 90° respectively. The anisotropy values thus estimated are found to be small and negative. The values of $\epsilon(W)$ were determined at each beta energy using the relationship

$$\epsilon(W) = \frac{2A(W)}{A(W)+3}$$

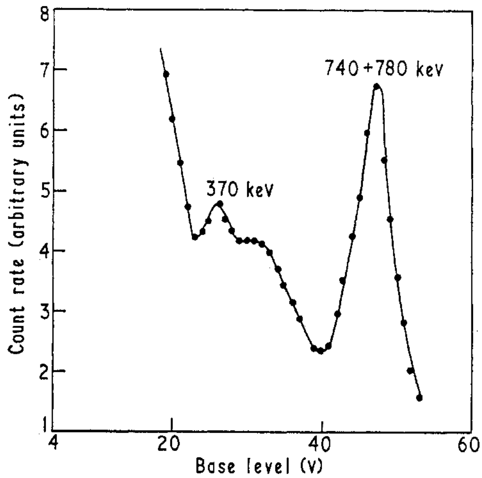

Figure 2. The singles gamma spectrum from ^{99}Mo.

and were corrected for the finite sizes of the beta and gamma detectors. The differential correlation coefficients thus obtained are summarized in table 1, in their final form. In the

Table 1. Differential correlation results

Energy (kev)	Energy (m_0c^2 units)	$\epsilon(W)$	$\epsilon'(W) = \epsilon W/P^2$
450	1·88	$-0{\cdot}023 \pm 0{\cdot}006$	$-0{\cdot}017 \pm 0{\cdot}005$
500	1·98	$-0{\cdot}023 \pm 0{\cdot}006$	$-0{\cdot}016 \pm 0{\cdot}004$
550	2·08	$-0{\cdot}034 \pm 0{\cdot}007$	$-0{\cdot}022 \pm 0{\cdot}005$
600	2·17	$-0{\cdot}023 \pm 0{\cdot}008$	$-0{\cdot}014 \pm 0{\cdot}005$
650	2·27	$-0{\cdot}027 \pm 0{\cdot}008$	$-0{\cdot}015 \pm 0{\cdot}005$
700	2·37	$-0{\cdot}023 \pm 0{\cdot}009$	$-0{\cdot}012 \pm 0{\cdot}005$

same table the values of $\epsilon'(W)$ ($=\epsilon W/P^2$) are also included. $\epsilon'(W)$ is known as the reduced correlation coefficient which indicates the P^2/W dependence of $\epsilon(W)$. Here P and W are the electron momentum and energy, respectively, and $P^2 = W^2-1$. W is expressed in m_0c^2 units, m_0 being the rest mass of the electron. The behaviour of $\epsilon(W)$ and that of

$\epsilon'(W)$, as a function of W, are shown in figures 3 and 4 respectively. From these figures one can see the energy independence of both $\epsilon(W)$ and $\epsilon'(W)$ functions within experimental errors.

5. Discussion

The present beta transition involved in a spin change of unity and parity change is of non-unique first-forbidden type and four matrix elements belonging to tensor ranks $\lambda = 1$ and $\lambda = 2$ govern this transition.

The beta–gamma angular correlation coefficient in the angular distribution (Kotani 1959)

$$W_{\beta-\gamma}(\theta) = 1+\epsilon(W)\mathrm{P}_2(\cos\theta)$$

is given by

$$\epsilon(W) = \frac{P^2}{W}\,\frac{R_3+eW}{C'(W)}$$

and

$$C'(W) = Kc'(W).$$

R_3, e and K are combinations of matrix elements defined in Kotani (1959) and $C(W)$ is the shape factor.

For non-unique first-forbidden beta transitions if the ξ approximation holds good (Kotani and Ross 1958) one can expect (i) an energy-independent shape factor lying within ξ, (ii) a small beta–gamma anisotropy and (iii) $\epsilon'(W) = \epsilon(W)\ W/P^2 = R_3 =$ constant.

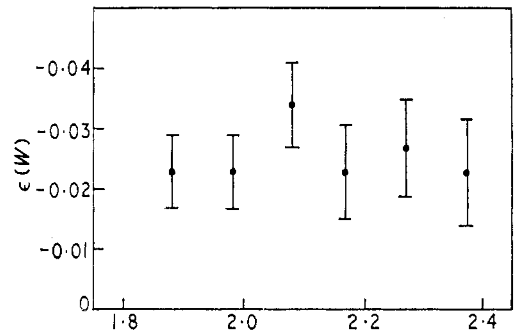

Figure 3. $\epsilon(W)$ against energy in m_0c^2 units.

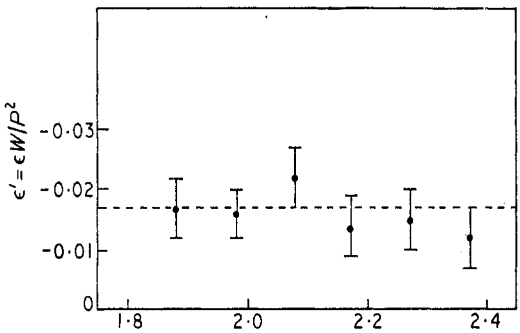

Figure 4. $\epsilon'(W)$ ($= \epsilon(W)\ W/P^2$) against energy in m_0c^2 units.

From the behaviour of $\epsilon'(W)$ shown in figure 4 it can be seen that $\epsilon'(W)$ is independent of energy within experimental errors. The shape-factor measurements on the 880 kev beta transition in ^{99}Mo made by Nagarajan (1968, unpublished) also indicate the near independence of $C(W)$ on energy. Thus both $C(W)$ and $\epsilon'(W)$ functions are consistent with the validity of the ξ approximation.

The $\frac{3}{2}^-$ state in ^{99}Tc, fed by the 880 kev beta transition in ^{99}Mo decay was fairly well established (Dorikens-van Pract *et al.* 1967) as arising out of the coupling between the 2^+ phonon state of ^{98}Mo core and $\frac{1}{2}^-$ pure nucleon (proton) state. This coupling results in $\frac{5}{2}^-$ and $\frac{3}{2}^-$ states at excitation energies 1150 and 520 kev respectively, as observed in ^{99}Tc. The ground state of ^{99}Mo is an $s_{1/2}$ state. The low intensity and the large $\ln ft$ value of the 880 kev beta transition in ^{99}Mo may perhaps be due to the circumstance in which the final state $\frac{3}{2}^-$ in the daughter nucleus is not a particle one.

Finally, it may be concluded that the present results on the energy dependence of the angular correlation for the $\frac{1}{2}^+(\beta)\frac{3}{2}^-(\gamma)\ \frac{1}{2}^-$ cascade in ^{99}Mo show that the 880 kev beta transition fits into the ξ approximation.

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