of the result and dividing by the intensities as in Eq. (8). We have extended this method to include elliptically polarized radiation for multipole mixtures and the pure multipoles which are special cases of these mixtures. Since Eqs. (3) and (13) are perfectly general, the method may be extended to multipole mixtures of any order. Possible use of these results in experiments has also been briefly described.

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Beta Decay of Y^{90m}†

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An 0.620-MeV β^- branch has been observed to compete with the previously reported gamma decay from the 3.14-h Y^{90m}. The calculated values, derived from the shell model for the branching ratio $[(0.620\text{-MeV}\,\beta^-)/(0.482\text{-MeV}\,\gamma)=1.16\times10^{-3}]$ and the $\log ft$ (7.54) are compared with the experimental values of $3.8\pm1\times10^{-3}$ and 7.04 ± 0.13, respectively. The small discrepancy is probably due to impurities in the shell-model configurations assumed for the transition.

INTRODUCTION

THE 0.685-MeV ${}_{39}Y_{51}{}^{90m}$ level ($T_{1/2}=3.14$ h) has been shown[1–4] to gamma decay to an 0.203-MeV level and then to the ground state in a simple cascade with no measurable crossover. Spins and parities of 7^+ for the 0.685 MeV level and $3-$ for the 0.203-MeV level have been established by the above groups, the ground-state spin and parity being previously established as $2-$ by Bartholomew.[5] From shell-model considerations, the 39th proton is in the $p_{1/2}$ shell and the 51st neutron is in the $d_{5/2}$ shell outside of a $g_{9/2}$ closed shell of 50 neutrons.[6] This implies that the $2-$ ground state and the $3-$ state result from the $(p_{1/2}d_{5/2})$ configuration. The simplest assumption as to the configuration of the $7+$ isomeric level is to promote one proton into the $g_{9/2}$ shell, creating the $(g_{9/2}d_{5/2})$ configuration, and allowing the gamma decay from this state to involve a change only in the state of one nucleon.

The levels in ${}_{40}Zr_{50}{}^{90}$ have been studied by Ford,[7] Sheline,[8] Lazar *et al.*,[9] Bjørnholm *et al.*,[10] and Bayman *et al.*[11] In his study of this nucleus, Ford[7] has shown that the low-lying states in Zr^{90} should be determined by the proton configurations $(p_{1/2})^2$, $(g_{9/2})^2$, and $(p_{1/2}g_{9/2})$. Sheline[8] first observed the low-lying expected levels of $(1.752\text{ MeV})_{0+}$, $(2.182\text{ MeV})_{2+}$, and $(2.315\text{ MeV})_{5-}$ by populating them through the decay of Nb^{90}. Due to its spin, the $5-$ level can be unambiguously assigned to the $(p_{1/2}g_{9/2})$ orbital. Experimentally, this level was found to decay 84% to the ground state with an $E5$ gamma and 14% to the 2.182-MeV level by an $E3$ gamma transition. Furthermore, it was shown[8–10] that the ground state and the first excited state should both be mixtures of $(g_{9/2})^2$ and $(p_{1/2})^2$ configurations.

The relative population of the ground and first excited $0+$ states in Zr^{90} by the Y^{90} ground state[12] through β^- decay and by the Zr^{90} $(2.182)_{2+}$ state through γ decay, establishes[8,10,11] that the ground-state configuration is $63\%\ (p_{1/2})^2+37\%(g_{9/2})^2$.

THEORETICAL

By examining the initial and final configurations of the states involved in the beta transition between the ground states of Y^{90} and Zr^{90}, it can be seen that this transition can be described as the transformation of a $d_{5/2}$ neutron into a $p_{1/2}$ proton. In a similar fashion, the $(g_{9/2}d_{5/2})_{7+}$ isomeric state in Y^{90} could be expected to decay into the $(p_{1/2}g_{9/2})_{5-}$ excited state in Zr^{90} by a $d_{5/2}$ neutron transforming via a new beta transition into a $p_{1/2}$ proton.

Not only will it be reasonable to expect that the $\log ft$ value for the two beta decays should be similar, but that one should be able to predict the $\log ft$ value of the new transition by using the $\log ft$ value of the ground-state transition after including the percentage (63%) of mixing of the ground-state configuration in Zr^{90} and a geometrical factor. The geometrical factor is needed

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to account for the effect of having a difference in the initial and final spins of the residual nuclei.

The beta transition probability is

$$T_{fi}(\beta)=\frac{1}{(2J_i+1)}\sum_{M_fM_i}|\langle J_fM_fj_{1'}j_{2'}|T_2(1)|J_ij_1j_2M_i\rangle|^2,$$

where

	(2.25-MeV β^-) (initial)	(final)	(0.620-MeV β^-) (initial)	(final)
(neutron → proton)	$j_1=5/2$,	$j_1'=1/2$,	$j_1=5/2$,	$j_1'=1/2$,
(proton → proton)	$j_2=1/2$,	$j_2'=1/2$,	$j_2=9/2$,	$j_2'=9/2$,
	$J_i=2$,	$J_f=0$,	$J_i=7$,	$J_f=5$.

This can be reduced to a ratio of terms of the form:

$$T_{fi}(\beta)\sim[(2J_f+1)/(2J_i+1)](2j_1'+1)(2J_i+1)W^2 \times(j_1J_ij_1'J_f;j_22)|\langle j_1'||T_2||j_1\rangle|^2.$$

The value of the ratio is found to be:

$$T_{fi}(\beta)_{2.25}/T_{fi}(\beta)_{0.620}=5/3.$$

Applying this ratio to the ft value (already corrected for configuration mixing) yields the calculated ft value, which is quoted in Table I.

EXPERIMENTAL PROCEDURE

To determine the experimental branching ratio, and thereby obtain the logft value of the new beta transition from Y^{90m}, it is most convenient to look for the decay of the 5− level in Zr^{90} populated in the branching from Y^{90m}.

The activity was produced by the reaction $Y^{89}(d,p)Y^{90}$ using the deuteron beam of the Florida State University Tandem Van de Graaff Accelerator.

The target was prepared, using a high-purity specimen of naturally occurring Y^{89} metal, by pressing metal shavings into a disk of 1-cm diameter and weighing approximately 200 mg. Beam currents available at the target were on the order of 1–3 μA, at 9–9.5 MeV. A bombarding time of 3 h (approximately one half-life) was chosen to minimize the production of other nuclides through (d,n) and $(d,2n)$ reactions. The maximum yield for the (d,p) reaction was at approximately 10-11 MeV, from excitation curves run by Riley and Linder,[13] so the maximum available bombarding energy was used on each run.

To remove impurities after bombardment, the activity was dissolved in 12M HCl, after which it was passed through an ion exchange column composed of Dowex 1×10, 200–400 mesh anion resin. The resin, by forming chloride complexes with Zr (the major contaminant), retained the Zr and allowed the Y^{90} activity to pass through. The drops were collected and, by identifying the 0.482-MeV γ ray in Y^{90}, the fractions containing the maximum amount of the activity were combined to form the sample to be counted. Using this method, it was possible to eliminate most of the zirconium which interfered with the measurement of the 0.482-MeV peak.

Table I. Comparison of theory and experiment.

Parameter	Calculated	Experimental
Branching ratio	1.16×10^{-3}	$(3.8\pm1)\times10^{-3}$
logft	7.54	7.04 ± 0.13

The counting was conducted with the source and the 3-×3-in. NaI (Tl activated) scintillation crystal placed inside of a shield composed of mercury and lead, the shield being necessary to reduce the residual background (Tl^{208}) in the high-energy region to a level consistent with the requirements of the experiment. Provision was made in the chamber for insertion of lead absorber between the source and the crystal.

EXPERIMENTAL RESULTS

The 2.315-MeV gamma corresponding to the new beta transition was observed in two consecutive bombardments. The first bombardment was made for identification of the transition, while the second was made for more accurate half-life determination. Data from the first run indicated that several impurities, La^{140}, Na^{24} (see Fig. 1), and Zr^{89}, were present. The La^{140} is characterized by 1.58- and 2.50-MeV γ rays having half-lives of 40-h Zr^{89}, still present in a small amount despite the chemical separation, has an 0.920-MeV γ-ray and an 0.511-MeV annihilation peak with half-lives of 79 h.

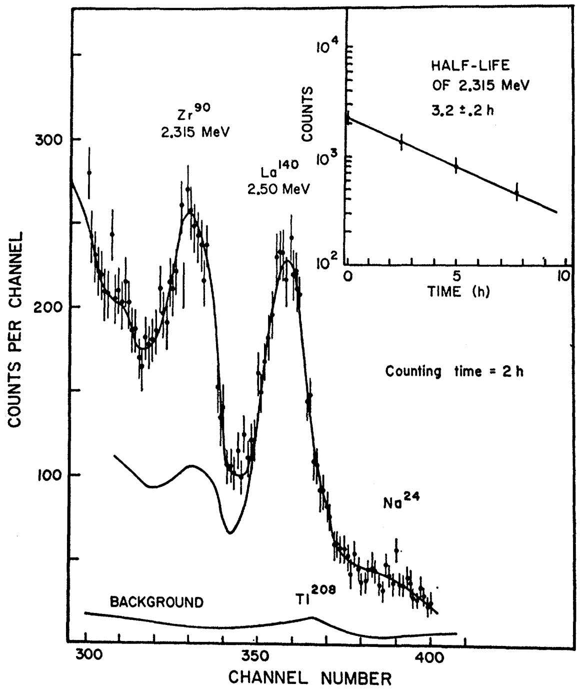

Fig. 1. High-energy gamma spectrum. Insert: Experimental half-life of 2.315-MeV level.

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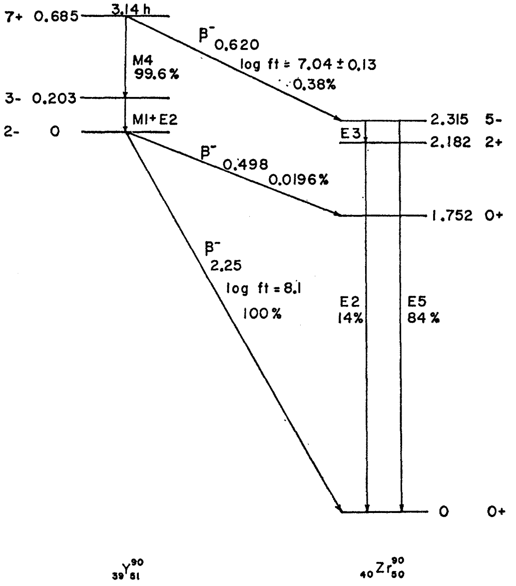

FIG. 2. Revised level scheme for Zr^{90}.

Na^{24}, present in a very small amount, has γ rays at 2.76 and 1.37 MeV with half-lives of 15 h.

The La^{140}, almost identical to yttrium chemically, was not removed and was used in the absorption ratio measurement. To determine the half-life of the rapidly decaying 2.315-MeV peak, four counting runs were made as quickly as possible after bombardment and chemical separation. Each run was of a 2-h duration with a 1.6-cm lead absorber between the source and the crystal to attenuate the intense low-energy gammas and therefore decrease the counting rate to a level compatible to the detecting and analyzing system. Following these, 5-min runs were made without the absorber to measure the intensity of the 0.482-MeV peak.

The general procedure followed in analyzing the data was to: (a) measure intensity of 2.315-MeV peak with lead absorber; (b) measure the intensity of the 0.482-MeV peak without lead absorber; (c) measure absorption coefficient for this geometry and energy (2.315 MeV); (d) correct the data for the relative efficiency of the crystal at these energies.

It is found that the major background contribution to the spectrum in the region of the 0.482-MeV peak comes from bremsstrahlung. The contribution from the external background is negligible in this region, but there does exist a small 0.511-MeV annihilation peak from Zr^{89}. The intensity of the 0.482-MeV peak was measured by first subtracting the 0.511-MeV peak and then using the bremsstrahlung as the base of the curve. A Gaussian was fitted to the curve (the full energy peak) and its area was measured graphically. The total counting rate was then corrected for decay time.

The statistics of the four runs made for the half-life determination of the 2.315-MeV peak rapidly became very poor. To obtain the intensities for this peak, the background (run for ten hours to build up good statistics) and the 2.50-MeV peak were subtracted from the data. Then the area of a Gaussian curve best fitting the residual peak was measured.

The experimental absorption coefficient for 2.315 MeV was measured by waiting until all of the 3.2-h activity had decayed and then counting the 40 h, 2.5-MeV La^{140} peak with and without absorber for 10 h yielding a value, corrected for a slight energy dependence, of $I/I_0 = 1/3.64 (\mu = 0.182\ \text{cm}^2/\text{g})$.

DISCUSSION

The presence of a β^- branch in Y^{90m} has been clearly established. Not only does one see the characteristic 2.315-MeV gamma expected from the depopulation of the 5− Zr^{90} state, but also the half-life measured for the decay of the 2.315-MeV gamma is 3.2±0.2 h, which is in agreement with the value of 3.14 h observed as the half-life of Y^{90m}. Table I gives the comparison of the theoretically predicted $\log ft$ value and the experimentally measured $\log ft$ value of this new transition, as well as the respective branching ratios.

Figure 2 gives the revised decay scheme containing the new β^- branch from Y^{90m}. The discrepancy observed between the theoretical and experimental values probably arises from several sources. Perhaps the most serious difficulty involves impurities in the four shell model states assumed to be involved in the two β^- transitions considered. Determinations of $\log ft$ values between similar shell model states in different nuclei are known to differ considerably. These differences are usually considered to be due to impurities in the wave functions of the states.

The complex geometry used in the experiment with the presence of considerable material which absorbs and scatters the radiation, complicates the determination of the absorption ratio, and the measurement of the intensity of the 2.315-MeV gamma. The change in the parameters of the Gaussian curve approximating the full energy peak with and without absorber, necessitated approximations in the intensity determination for both the 2.315-MeV gamma and the 2.50-MeV gamma used for the absorption coefficient measurements. When these factors are considered and especially if one compares $\log ft$ values between similar shell model states in other nuclei, the values 7.54 and 7.04±0.13 calculated and experimentally observed, compare satisfactorily.

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