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Gyromagnetic Ratio of the 3.5×10^{-9} sec State and Other Angular Correlation Measurements of Tc^{99}†

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The gyromagnetic ratio of the 181-kev state of Tc^{99} is found to be $+1.5\pm0.2$ nuclear units. The angular correlation pattern obtained for the 740- and 181-kev pair of gamma rays is $W(\theta)=1+(0.067\pm0.004)P_2(\cos\theta)+(0.020\pm0.005)P_4(\cos\theta)$ and that of the 740- and 140-kev pair of gamma rays is $W(\theta)=1-(0.107\pm0.010)\times P_2(\cos\theta)$.

THE gyromagnetic ratio of the 181-kev state[1] of Tc^{99} (Fig. 1) has been measured by observation of the perturbation of the angular correlation pattern of the 740- and 181-kev gamma rays by a magnetic field applied perpendicularly to the plane of the gamma rays. Also, the angular correlations of the 740–181 kev and the 740–140 kev gamma-ray pairs have been studied in an effort to obtain information about the spin and parity assignments of the levels of Tc^{99}.

The gamma-ray cascades in Tc^{99} were obtained following the beta decay of 68-hour Mo^{99}. Ordinary 0.008-inch molybdenum wire was irradiated with neutrons in the Argonne Research Reactor CP-5 to form Mo^{99} by neutron capture. The activated molybdenum was partially dissolved in 6*N* nitric acid. After repeated centrifuging and separation, more 6*N* nitric acid was added. The centrifuging process and separation were repeated. In this way liquid sources were obtained[2] which gave reproducible results and the maximum observed anisotropies.

The coincidence circuit and counting equipment have been described previously.[3] The pulse-height analyzer of the counter which detected the 740-kev gamma ray was set to accept pulses corresponding to radiation from 500 to 950 kev. An absorber of lead 0.32 cm thick was used on this counter to reduce back-scattering contributions to the observed coincidence rates. The counter which detected the 181-kev gamma ray was biased to select pulses caused by radiation ranging from 180 kev to 240 kev. This window selection reduced the contribution of the 140-kev gamma ray to a negligible amount. In order to study the 740–140 kev cascade, the lower energy counter was biased to accept from 90 to 130 kev. This reduced the contribution from the 181-kev gamma ray to about 8%.

The angular distribution, corrected for the solid angle of the detectors, was determined to be

$$W(\theta)=1+(0.067\pm0.004)P_2(\cos\theta)+(0.020\pm0.005)P_4(\cos\theta) \quad (1)$$

for the 740–181 kev cascade, while for the 740–140 kev cascade the result was

$$W(\theta)=1-(0.107\pm0.010)P_2(\cos\theta). \quad (2)$$

These results and the internal-conversion data[4,5] are consistent with a ground-state spin of $9/2^+$ and spins of $\frac{7}{2}^+$, $\frac{5}{2}^-$, and $\frac{1}{2}^-$ for the 140-, 181-, and 921-kev levels of Tc^{99}, respectively, with the 181-kev gamma ray a mixture of *M*2 with 0.36% *E*3 ($\delta=+0.06$) radiation. The 140-kev transition is[4] *M*1 with 0.25%

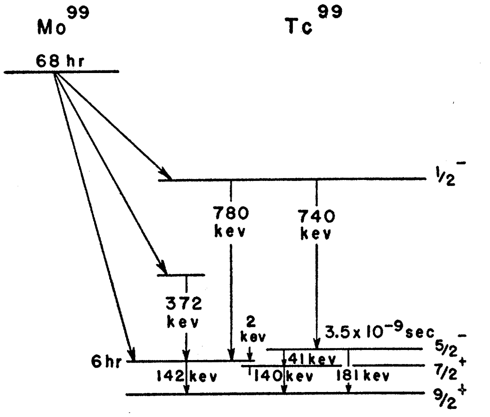

FIG. 1. Decay scheme of Tc^{99} from Varma and Mandeville.[1]

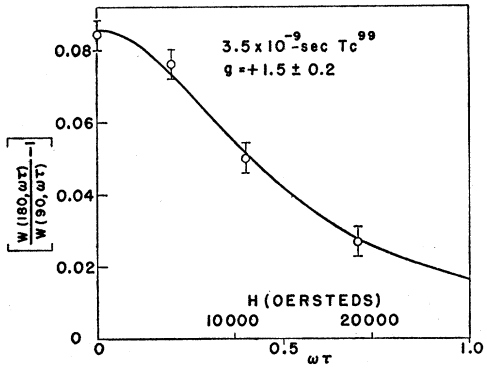

FIG. 2. Attenuation of the 740–181 kev gamma-gamma anisotropy by the applied magnetic field.

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$E2$ ($\delta=+0.05$) if the 41-kev radiation is pure $E1$. If $M2$ mixing is allowed in the 41-kev transition, then reasonable fits can be obtained with two parameters. If, for example, the latter were 60% $M2$, the 140-kev transition would have to contain 2% $E2$ in order to fit the angular-correlation data.

The observed attenuation of the anisotropy of the 740–181 kev gamma-ray cascade as a function of the magnetic field applied perpendicularly to the plane of the gamma rays is shown in Fig. 2. The experimental curve has been fitted by a theoretical curve which takes account of the solid angle of the detectors. The fit is obtained by relative adjustment of the horizontal scales. The result for the gyromagnetic ratio of the 3.5×10^{-9}-sec state is $g=+1.5\pm0.2$ nuclear units. The sign of g was obtained from measurements at 135° and 225° with a field of 10 000 oersteds.

The measured gyromagnetic ratio and the assignment of spin $\frac{5}{2}$ lead to a magnetic moment $\mu=3.8\pm0.5$ nuclear magnetons. This value lies just below the upper Schmidt limit, suggesting positive parity for the state if the spin is indeed $\frac{5}{2}$. As our proposed spin scheme assigns negative parity, we would like to see more precise internal conversion coefficients for the 41-, 181-, and 740-kev gamma rays. This would provide a better test of the spin and parity assignments. If the $\frac{5}{2}-$ assignment for the 181-kev level is correct, the magnetic moment is surprisingly large.

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Polarization of Bremsstrahlung from Polarized Electrons

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We analyze the polarization of bremsstrahlung emitted from polarized electrons, in the Born approximation. Spins of the final electron are summed over. Differential cross sections are given, and are integrated over final electron directions. The results are valid for all electron energies, subject only to the limitations on the validity of the Born approximation. Screening is taken into account by using an exponential atomic form factor. Methods for relativistic spin description are discussed.

I. INTRODUCTION

BREIT[1] seems to have been the first to point out that polarized electrons can produce circularly polarized bremsstrahlung. This subject, however, became of interest only recently when it was discovered that electrons from β decay[2] and $\mu-e$ decay[3] are polarized. One of the first experiments to determine the polarization of these electrons[4] consisted in measuring the circular polarization of the bremsstrahlung emitted. The evaluation of this experiment was based on results of McVoy[5] who calculated in Born approximation the bremsstrahlung circular polarization for longitudinally polarized electrons and forward emission of the radiation. Calculations of this type have subsequently been extended: differential cross sections were published by Claesson[6] and Böbel,[7] and integrated cross sections for high-energy electrons by the authors[8] and by Olsen and Maximon[9]; the last reference is the only work which goes beyond the Born approximation and takes Coulomb corrections into account. In the following, we derive the differential cross section of bremsstrahlung for polarized initial electrons and polarized photons (Sec. III), and integrate it over final electron directions (Sec. IV). In Sec. II, we give a short summary of the methods used in the literature for describing the spin of relativistic particles, as well as a discussion of projection operators. In Sec. V, the polarizations of the emitted radiation are analyzed. This includes the linear polarization, which has been discussed previously by May[10] and by Gluckstern and Hull.[11] Whereas May limited his investigation to energetic electrons, the latter authors considered all electron energies, but introduced the effect of screening in an intuitive way which is reasonable for energies of a few Mev only. Our treatment gives a correct account of the screening, using an exponential atomic form factor.

As to experimental applications of our results, they might, on the one hand, provide a more accurate theory for use in the experiment of Goldhaber *et al.*[4] than does that of McVoy; on the other hand, they could represent a means for determining transverse electron polarization

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