BETA-RAY ASYMMETRY FROM ORIENTED ^{110m}Ag†*

T. F. Knott‡, H. R Andrews, E. J. Cohen, and F. M. Pipkin
Lyman Laboratory, Harvard University, Cambridge, Massachusetts 02138

and

D. C. Santry
Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada
(Received 16 June 1970)

A new technique for the study of the beta rays emitted by polarized nuclei is presented. This technique uses two silicon detectors arranged in coincidence so as to discriminate against gamma rays and back scattering from the detectors. This technique has been used to study the asymmetry of the beta rays in the decay of ^{110m}Ag.

One of the most powerful techniques for studying the beta-decay interaction and for measuring beta-decay matrix elements is the observation of the asymmetry of the beta rays emitted by polarized nuclei.[1,2] Because of the difficulty of the measurements this technique has not been extensively developed.[3] We report here the first measurements with a new technique which is generally applicable and which will make possible precision measurements of the beta-ray asymmetries from polarized nuclei. In particular we report a study of the beta-ray asymmetry from polarized ^{110m}Ag.

Figure 1 shows a diagram of the apparatus.[4] The ^{110m}Ag nuclei were oriented as impurities in an iron foil which was cooled to roughly 15 mdeg K by thermal contact with a demagnetized chromium potassium alum salt pill. High specific activity ^{110m}Ag from which all ^{110}Cd had been chemically separated was ion implanted into 75-μm foils using the Chalk River isotope separator. The most probable penetration depth of 40-keV Ag ions was 10 μg/cm^2; this makes beta-ray multiple scattering in the source negligible. The iron foil is soldered to the end of a copper tube; the diameter of the source is smaller than the inner diameter of the copper tube.

A combination of two commercial silicon detectors was used to detect the electrons. As shown in Fig. 1 these detectors were mounted on a thermal insulator in the 1 to 4°K vacuum space of the cryostat. A heater consisting of a 470-Ω, $\frac{1}{2}$-W resistor was used to maintain the detectors at a temperature near 77°K so that their resolution was optimum. The first, or "thin," detector was a 200-μm thick totally depleted silicon transmission detector (Simtec 1002) which had an active area of 1 cm^2. The second, or "thick", detector was a lithium-drifted silicon detector with a depletion depth of 0.5 cm and a sensitive area of 1 cm^2 (Simtec K-14). The two detectors were operated in coincidence with the single-channel window on the thin detector set so as to accept only those energies corresponding to single passage of an electron through the detector. This arrangement gave a large discrimination against gamma rays and back scattering from the thick detector. The domains in the iron foil were aligned by applying an external magnetic field of 1600 G by means of a small superconducting coil. The electrons were observed at 45° to the axis of polarization. The temperature of the foil was determined by simultaneously observing the gamma rays from ^{110m}Ag with a 30-cm^3 Ge(Li) detector. Figure 2 shows the decay scheme of ^{110m}Ag. For the determination of the sample temperature the known electric quadrupole gamma rays were used and the anisotropy was measured by observing the gamma rays emitted at zero degrees to the axis of orientation. Demagnetizations were made in which the direction of emission of the observed electrons was alternately 45° and 135° to the direction of polarization. The electron anisotropy was then analyzed in terms of the expression[1,3,5]

$$\epsilon(\theta) = \sum_{k=1}^{2} b_k U_k F_k B_k P_k(\cos\theta);$$
$$= \sum_{k=1}^{2} (v/c) A_k B_k P_k(\cos\theta).$$

Figure 3(a) shows the beta-ray spectrum observed with the silicon detector. Figure 3(b) shows the coefficient A_1 determined from the orientation data. Wherever appropriate the data have been corrected for the conversion electrons so as to obtain a pure beta-ray anisotropy. The gamma-ray response was measured by putting an absorber sufficiently thick to stop all electrons in front of the detector and then measuring its response. The gamma-ray response is shown in Fig. 3(a). The data in Fig. 3(b) have been corrected for contamination due to gamma rays.

There are two important beta-ray groups in the decay of ^{110m}Ag: the low-energy $6^+ \rightarrow 6^+$ 531-

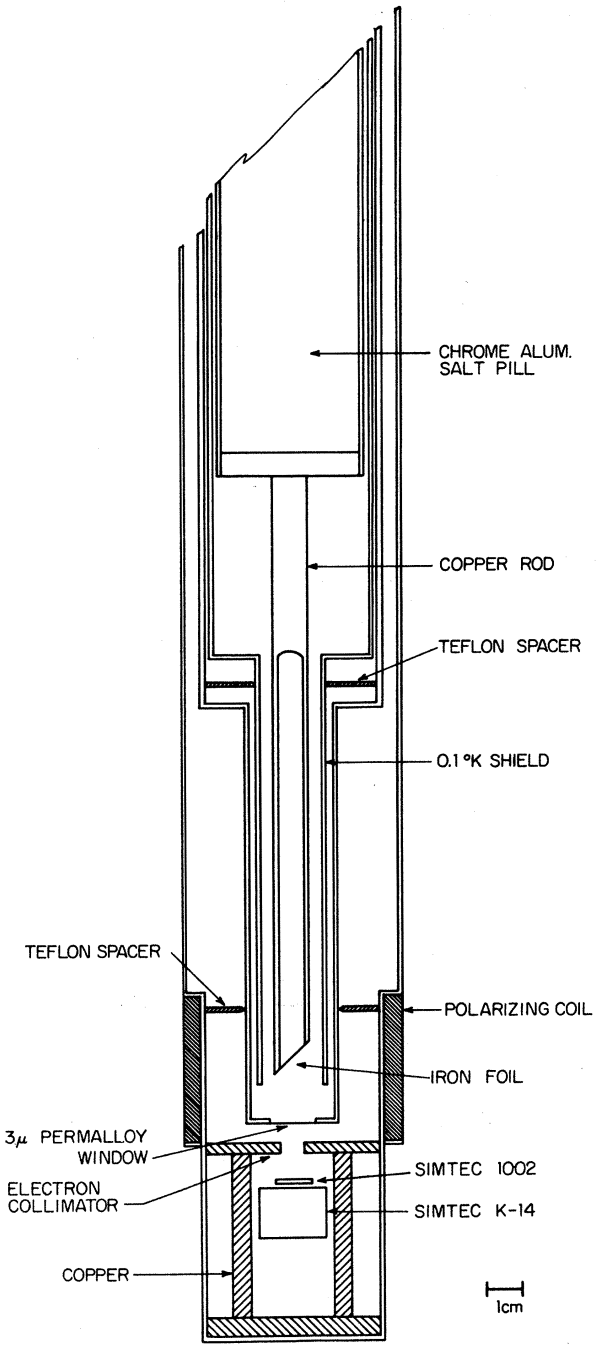

FIG. 1. A diagram of the orientation apparatus showing the relative location of the source, the detectors, the electron collimator, and the polarizing coil.

keV transition and the high-energy $1^+ \rightarrow 0^+$ ^{110}Ag 2.89-MeV transition. The 531-keV transition is so intense that it dominates the competing sources of electrons; the 2.89-MeV transition is in a region where there is no confusion due to other transitions.

The 531-keV transition is in general a Fermi–Gamow-Teller mixture. The relationship between the beta-ray asymmetry and the ratio of the Fermi to Gamow-Teller matrix elements is given by the equation

$$A_1 = -0.089\,08\left[\frac{1+12.962X}{1+X^2}\right],$$

where

$$X = C_V M_F / C_A M_{GT}$$

is the ratio of the Fermi to the Gamow-Teller matrix element. From the observed anisotropy, $A_1 = -0.055 \pm 0.010$, we conclude that

$$X = -0.029^{+0.009}_{-0.008} \text{ or } +21.0^{+4.7}_{-3.2}.$$

The error is a combination of the statistical error and an estimate of the uncertainty due to source backscattering and to the Compton electrons. The comparable result determined from a beta-gamma circular polarization experiment is[6]

$$X = -0.02 \pm 0.03 \text{ or } -10.3^{+2.3}_{-4.1}.$$

The orientation measurement indicates that the first of the two values is the correct one. The agreement between the measurements is satisfactory and lends credence to both techniques.

The 2.89-MeV transition is a pure Gamow-Teller transition and has a completely predictable anisotropy,

$$A_1 = -0.8164,$$

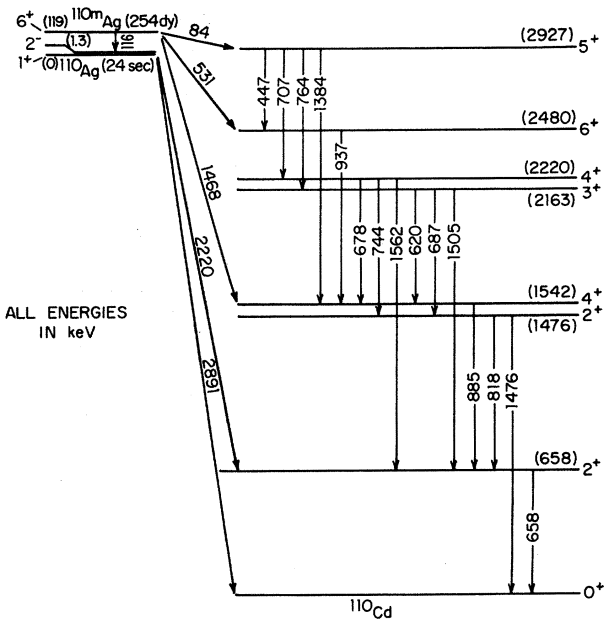

FIG. 2. The energy level diagram for ^{110m}Ag.

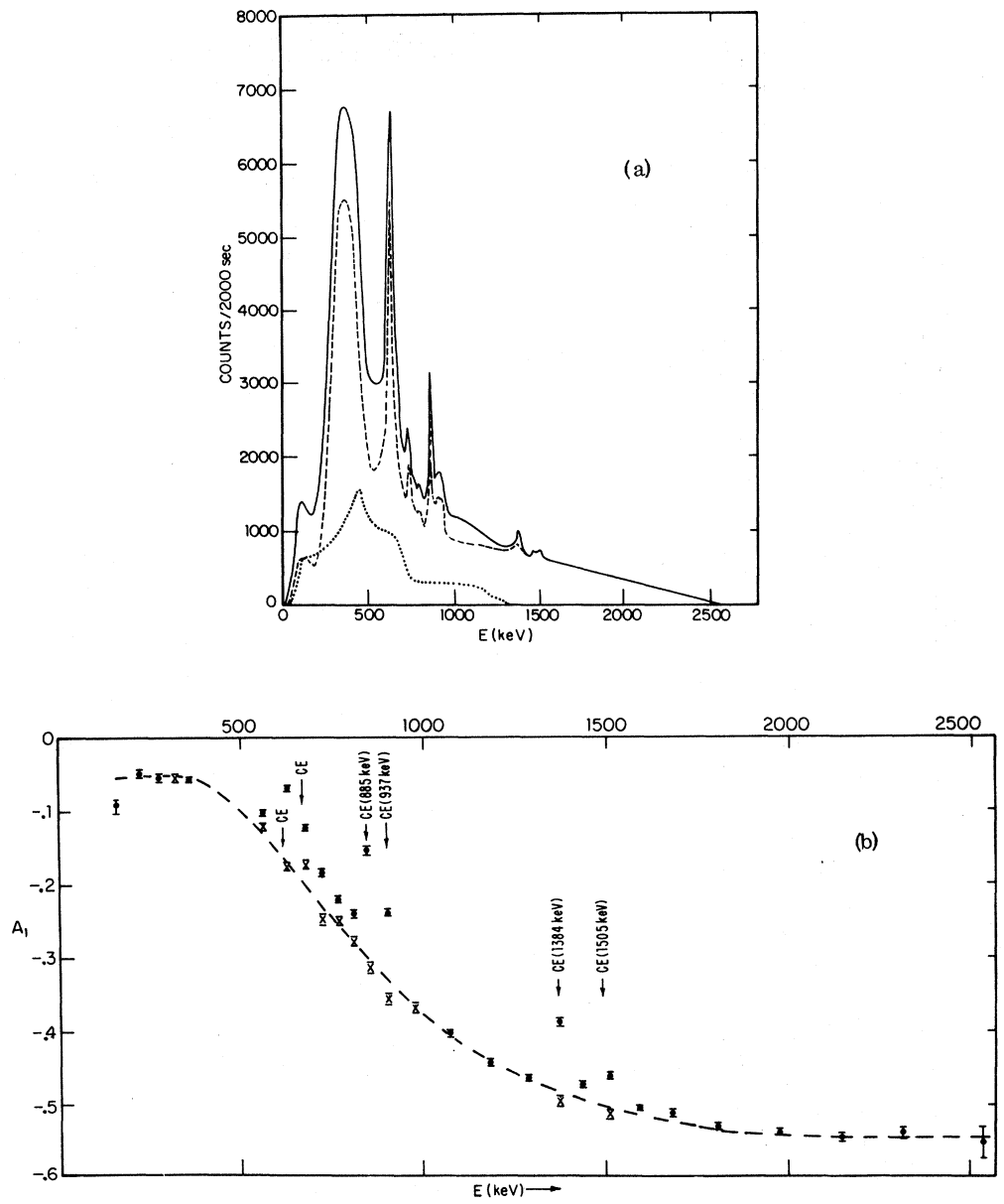

FIG. 3. (a) The beta-ray spectrum as observed with the two silicon detectors in coincidence. The heavy line is the total response, the dotted line is the gamma-ray response, and the dashed line is the spectrum obtained by subtracting out the gamma rays. The gamma-ray response was observed by putting an obstacle sufficiently thick to stop all the electrons in front of the detector. (b) The observed beta-ray anisotropy A_1 as a function of the energy of the beta rays. The solid dots indicate the raw data. The crosses show the data after they have been corrected for the presence of the conversion electrons.

if there are no higher-forbidden corrections. The analysis of the transition is, however, complicated by the long life of the parent 1^+ ground state of ^{110}Ag. If the multipolarities of the 116-keV $6^+ \rightarrow 2^-$ and of the 1.3-keV $2^- \rightarrow 1^+$ transitions are known,[7] then the initial orientation parameters for the 1^+ state can be calculated. Because of relaxation processes these orientation parameters will then evolve in time towards the thermal equilibrium values determined by the sample temperature, the field at the silver nucleus, and the magnetic moment of the 1^+, ^{110}Ag ground state. The precise orientation parameters at the time of the decay will thus depend

on the relaxation time. We have used this model to understand the data for the 2.89-MeV beta transition. If we assume, as is suggested by the conversion-electron data, that the 116-keV transition is a pure $M4$ transition,[8] then we are forced to conclude that the 1.3-keV transition is an $E1$-$M2$ mixture. The data give a relationship between the mixing ratio and the relaxation time.

The gamma-ray data from this experiment taken when both ^{60}Co and ^{110m}Ag were present in the same foil can be used to determine a new value for the field at a silver nucleus in an iron lattice. We obtain

$$H(\text{Ag in Fe}) = -250 \pm 6 \text{ kG}.$$

The sign is determined by the sign of the electron anisotropy. This value for the field is in agreement with an earlier value determined by Westenbarger and Shirley.[9] They found

$$H(\text{Ag in Fe}) = -272 \pm 19 \text{ kG}.$$

In summary, a new technique for observing the beta rays from oriented nuclei has been developed. This technique uses commercially available silicon detectors operated in a cryogenic environment which are warmed to optimize their performance. A thin and thick detector are operated in coincidence so as to discriminate against back scattering and gamma rays. The detectors have proved to be quite reliable and have been successfully operated in this mode for more than a year.

We wish to acknowledge the aid of Dr. Ben Greenebaum in the early stages of the experiment. Longer reports on this experiment, the detectors, and the apparatus are being prepared for publication.

---

†Research supported in part by National Science Foundation Grant No. GP-15072.

*Based in part on a thesis submitted by one of the authors (T.F.K.) to Harvard University in partial fulfillment of the requirements for the Doctor of Philosophy in Physics.

‡Present address: Physics Department, University of British Columbia, Vancouver, British Columbia, Canada.

[1]S. R. de Groot, H. A. Tolhoek, and W. J. Huiskamp, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland, Amsterdam, 1965), Vol. II, p. 1199.

[2]F. M. Pipkin, J. Sanderson, and W. Weyhmann, Phys. Rev. 129, 2626 (1963).

[3]For a summary which includes most of the observations of beta rays emitted by oriented nuclei see H. F. Schopper, *Weak Interaction and Nuclear Beta Decay* (North-Holland, Amsterdam, 1966).

[4]For a description of the demagnetization apparatus see J. Hess, B. Greenebaum, F. M. Pipkin, and W. Weyhmann, Rev. Sci. Instrum. 36, 21 (1965).

[5]R. J. Blin-Stoyle and M. A. Grace, in *Handbuch der Physik*, edited by S. Flügge (Springer-Verlag, Berlin, 1957), Vol. 42, p. 556.

[6]H. Daniel, O. Mehling, and D. Schotte, Z. Phys. 172, 202 (1963).

[7]W. R. Kane and G. Scharff-Goldhaber, Phys. Rev. C 2, 314 (1970).

[8]Nuclear Data Sheets, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington, D. C.).

[9]G. A. Westenbarger and D. A. Shirley, Phys. Rev. 138, A161 (1965).