Gamma-Gamma Directional Correlation in Cd^{110}†

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(Received August 14, 1958; revised manuscript received December 18, 1958)

Directional correlation experiments have been performed for the 1385–885, 760–1510, and 940–885 kev gamma-ray cascades in Cd^{110}. Spins of 5, 6, 3, 4 have been assigned to the levels at 2935, 2490, 2170, and 1540 kev in the Cd^{110} level scheme. The 1385- and 1510-kev gamma rays are dipole-quadrupole mixtures.

INTRODUCTION

THE nuclide Ag^{110} has a 253-day isomeric state 116 kev above the 24-sec ground state.[1] The beta-transitions from the latter to the ground and first excited states of Cd^{110} have allowed shapes with $\log(ft)$ values of 5.3 and 4.4, respectively. Since Cd^{110} is an even-even nucleus, it is assumed that its ground state has zero spin and even parity. The spin-parity assignment of 1^+ to the ground state of Ag^{110} is consistent with the characteristics of the observed beta components, since the first excited state in Cd^{110} is definitely a 2^+ state. The multipole order of the 116-kev gamma-ray transition from the isomeric state has been classified in the literature as $M4$ on the basis of the lifetime of the state and the K/L ratio for the gamma ray. This leads to a spin-parity assignment of 5^- for the isomeric state. Recently,[2] however, a direct measurement of the spin of the state using the atomic beam magnetic resonance method, has given the value $I=6$, which suggests that the 116-kev gamma-ray is either $E5$ or $M5$. The K/L ratio for the radiation has been measured several times and is about 1.3.[3] Using Rose's tables of conversion coefficients, Sakai *et al.*[4] have calculated the ratio for several multipolarities. For $E5$ radiation of this energy, $K/L=0.185$, and for $M5$ radiation, $K/L=1.03$. The ratio for $M4$ radiation is 1.73, considerably higher than the observed value. Since the spin of the isomeric state is 6 units, the measured K/L ratio clearly supports an $M5$ classification for the transition.

The isomeric state in Ag^{110} also decays by the emission of two strong beta components[3,5] with end point energies of 89 kev and 530 kev, which lead to levels in Cd^{110} at 2935 and 2490 kev,[6] respectively. Two intense gamma-ray cascades proceed from the former state to the first excited state at 656 kev. The de-excitation of the 2490-kev level takes place mainly through the strong 940–885 kev cascade to the first excited state. The present investigation was undertaken to determine the spins of the 2935-, 2490-, 2170-, and 1540-kev levels in Cd^{110} by means of directional correlation measurements with these strong cascades.

Beyster and Wiedenbeck[7] made directional correlation measurements with Ag^{110m} using integral pulse-height selection, but were unable to assign spins to nuclear levels due to the complexity of the level scheme. Recently Sakai, Ohmura, and Momota[4] have performed similar experiments using differential pulse-height analysis. Spins were assigned to the levels mentioned above but, as will be shown later, their results disagree in part with the conclusions presented here. Some of this disagreement arises from Sakai's spin and parity assignment of 4^- or 5^- to the 253-day isomeric state in Ag^{110}.

Since the present investigation was completed, Knipper[8] has published the results of his directional correlation measurements in Cd^{110}. His conclusions are in general agreement with our own except for certain parity assignments. However, the bearing of the recent measurement of the spin of Ag^{110m} on the spin assignments in Cd^{110} was not discussed.

More recently Funk and Wiedenbeck[9] have carried out directional correlation studies with Ag^{110m}, obtaining results which agree in part with those presented in this paper.

EXPERIMENTAL PROCEDURE

The source material used in the directional correlation experiments was "spec. pure" silver metal (99.999% silver or better) which had been irradiated with thermal neutrons in the NRX reactor at Chalk River. Metallic sources with a strength of a few microcuries and a $AgNO_3$ source of comparable strength were used. The active material was sealed into polystyrene containers with walls about 3 mm thick. The containers were located on an aluminum post at the center of a detection system consisting of two scintillation counters mounted in a horizontal plane with their axes passing through the source position. One detector was movable, so that the angle θ between the counter axes could be

† Based in part on a thesis submitted by one of us (W.R.F.) to Queen's University in partial fulfillment of the requirements for the M.Sc. degree, September, 1957.

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[4] Sakai, Ohmura, and Momota, J. Phys. Soc. Japan **12**, 985 (1957).
[5] T. Azuma, Phys. Rev. **94**, 638 (1954).
[6] H. W. Taylor and S. A. Scott, preceding paper [Phys. Rev. **114**, 121 (1959)].
[7] J. R. Beyster and M. L. Wiedenbeck, Phys. Rev. **79**, 411 (1950).
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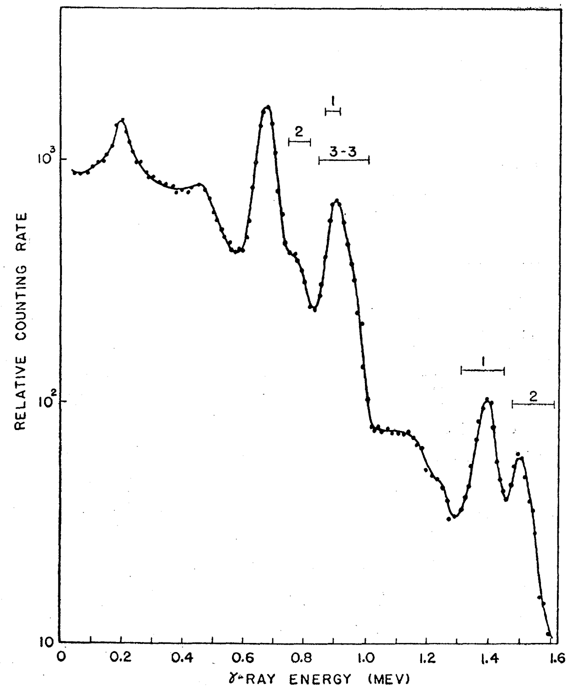

FIG. 1. Energy spectrum of the gamma radiation emitted by Ag^{110m}, obtained with a $1\frac{1}{2}$-inch×1-inch NaI(Tl) crystal. The gate positions used for the study of the 1385–885, 760–1510, 940–885 kev cascades are marked 1–1, 2–2, and 3–3, respectively.

varied in 5° steps from 90° to 180°. The source to counter distance was 5 cm.

Each of the two scintillation counters consisted of a $1\frac{1}{2}$-inch diam.×1-inch long NaI(Tl) crystal mounted on a 2-inch photomultiplier tube. The energy resolution for the Cs^{137} gamma-ray peak was about 8.5% for each counter. One counter was stabilized against drift by means of a counting rate difference stabilizing circuit designed by de Waard.[9a] The output pulses of the counters were fed into two linear amplifiers, each of which fed pulses to a single-channel pulse-height analyzer and a fast-slow coincidence circuit. The effective resolving time of the coincidence unit was 7.75×10^{-8} second. Three scalers permitted the simultaneous measurement of the coincidence and single counting rates and the data so collected were permanently recorded on film.

The experimental procedure was made fully automatic, with the movable detector being advanced from one angular position to the next after a predetermined number of coincidences had been recorded. The raw data, which were analyzed by the method of least squares, consisted of a set of values of the time required to collect a specified number of counts at the different angular positions used.

EXPERIMENTAL RESULTS

The pulse-height spectrum of the gamma radiation from Ag^{110m} obtained with one of the scintillation spectrometers is shown in Fig. 1. The prominent line at about 660 kev contains the strong 656-kev radiation plus a number of weaker components.[6] A poorly resolved line on the high-energy side of the peak is due to the 760-kev gamma ray and a much weaker 735-kev gamma ray. The line at 880 kev is due primarily to an 885-kev gamma ray, with the asymmetrical shape due to the presence of a 940-kev gamma ray of moderate intensity. Peaks at 1385 and 1495 kev are well defined, with the latter due to a superposition of two peaks, one associated with the intense 1510-kev gamma ray and the other with the somewhat weaker 1484-kev gamma ray.[6,10–12] A backscatter peak at about 200 kev is also in evidence.

A detailed study[6] of the decay scheme lead to the choice of gate positions for the spectrometers as shown in the figure. No correlation measurements were made with cascades involving the 656-kev gamma ray because of the large number of interfering cascades which would contribute to the coincidence rate.

Position 1-1 was used in the study of the 1385–885 kev cascade. With these gate positions, spurious coincidences can occur, however. A 1510-kev gamma ray may given a 1385-kev pulse in one counter, while the moderately strong 760–656 kev cascade contributes an 885-kev sum pulse to the other counter. Although some interference was encountered in the measurements made with this cascade, it did not prevent an unambiguous spin assignment for the levels concerned.

The 760–1510 kev cascade was studied with the gates at the positions labelled 2. A 1484-kev gamma ray has been reported in the literature, and has been interpreted[6] as a ground state transition from a level at 1476 kev established by Stelson.[13] Some evidence has been presented which suggests that the 1476-kev level is fed by a 735-kev gamma ray associated with de-excitation of a level at 2220 kev.[12,6] Although of low intensity, the 735–1484 kev gamma-ray cascade could contribute to the coincidence rate with the gates at positions 2. However, since the upper gate did not extend below 1480 kev, it was estimated that the interfering cascade could not contribute more than 5% of the observed counting rate.

The position labelled 3 was used to study the 940–885 kev cascade. A substantial interference was expected from the 1385–885 kev cascade. However, a knowledge of the directional correlation of the latter and the relative intensities of the gamma-ray lines involved, permitted a correction to be made to the observed coincidence rate which eliminated the interference.

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[12] Dzhelepov, Zhukovskiĭ, and Kondakov, Izvest. Akad. Nauk S.S.S.R. Ser. Fiz. **21**, 973 (1957); B. S. Dzhelepov and N. N. Zhukovskiĭ, Nuclear Phys. **6**, 655 (1958).

[13] P. H. Stelson (private communication).

McGowan[14] has looked for isomeric states in Cd^{110} and has placed an upper limit of 3×10^{-8} sec on the lifetime of any state excited by the beta decay of Ag^{110m}. Paul[15] has carried out a similar search and reduced the upper limit to 6×10^{-10} sec. In view of these results, no study of the effect of the physical nature of the source material on the observed directional correlations was deemed necessary.

For each of the three cascades studied, the coincidence rate was measued with the movable counter at angular positions of 90°, 110°, 130°, 145°, 160°, 170°, and 180° relative to the fixed counter. The results for the 1385–885 kev cascade after correction for the accidental rate are shown in Fig. 2. A total of 1.4×10^5 genuine coincidences were collected for this cascade using both metallic and crystalline sources. The expression $W'(\theta)=1+A_2'P_2(\cos\theta)+A_4'P_4(\cos\theta)$ was least-squares fitted to the experimental points, and is shown as a full curve in the figure. $W'(\theta)$ is the correlation function for the cascade before correction for the finite angular resolution of the counters. This correction was applied to $W'(\theta)$ following the method outlined by Rose,[16] and gave the corrected correlation function:

$$W(\theta)=1-(0.2837\pm0.0068)P_2(\cos\theta) - (0.0318\pm0.0096)P_4(\cos\theta). \quad (1)$$

Figure 3 shows the results obtained for the 760–1510 kev cascade. About 5×10^4 coincidences were collected in the study of this cascade. The uncorrected correlation function is shown as a full curve in the figure. After correction for angular resolution, the function $W(\theta)$ is

$$W(\theta)=1-(0.1627\pm0.0063)P_2(\cos\theta) - (0.0031\pm0.0098)P_4(\cos\theta). \quad (2)$$

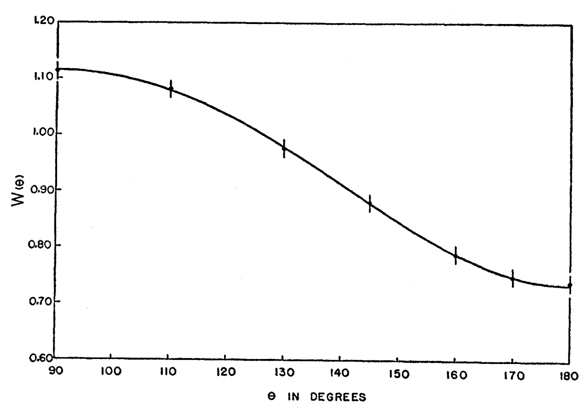

FIG. 2. Directional correlation of the 1385–885 kev gamma-ray cascade. The curve is the least squares fit of $W'(\theta)=1+A_2'P_2(\cos\theta)+A_4'P_4(\cos\theta)$ to the experimental points. No correction for finite angular resolution has been applied.

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[15] D. Paul, Royal Military College, Kingston (private communication).
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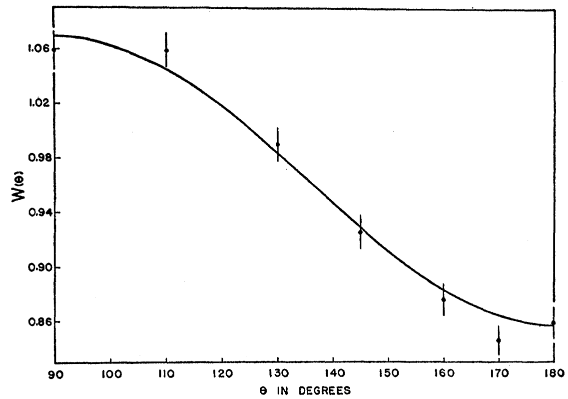

FIG. 3. Directional correlation of the 760–1510 kev gamma-ray cascade.

A total of 4×10^5 coincidences were recorded in the study of the 940-885 kev cascade. With the gates at positions marked 3, a large proportion of the observed coincidence rate is due to the interfering 1385–885 kev cascade. After subtracting the accidental rate from the observed rates at the seven angular positions used, a least-squares analysis of the data gave an uncorrected function

$$W'(\theta)=1+(0.0022\pm0.0027)P_2(\cos\theta) + (0.0023\pm0.0031)P_4(\cos\theta). \quad (3)$$

It will be noted that the observed angular distribution of coincidences is essentially isotropic. This situation is accidental in the present instance. The coefficients A_2' and A_4' are dependent on the degree of interference of the 1385–885 kev cascade. The choice of gate position for the experiment happened to give an interference which almost completely annulled the correlation being studied. By estimating the contribution of the interfering cascade and using its measured directional correlation [Eq. (1)], the function $W'(\theta)$ for the 940–885 kev cascade was determined. $W'(\theta)$ is given by

$$W'(\theta)(940\text{–}885) = W'(\theta)(\text{observed}) - kW'(\theta)(1385\text{–}885), \quad (4)$$

where k is a constant determined from the relative intensities of the gamma-rays involved. $W'(\theta)$, uncorrected for the angular resolution of the counters, is shown in Fig. 4 as a full curve. The large errors on the experimental points are due mainly to the uncertainty in k. When the resolution correction is applied to $W'(\theta)$, the correlation function is

$$W(\theta)=1+(0.093\pm0.023)P_2(\cos\theta) + (0.015\pm0.014)P_4(\cos\theta). \quad (5)$$

INTERPRETATION OF RESULTS

The spin of the 253-day isomeric state in Ag^{110} is now known to be 6 units.[2] Since the 89-kev beta transition is allowed with $\log(ft)$ value 5.6, the spin of the 2935-

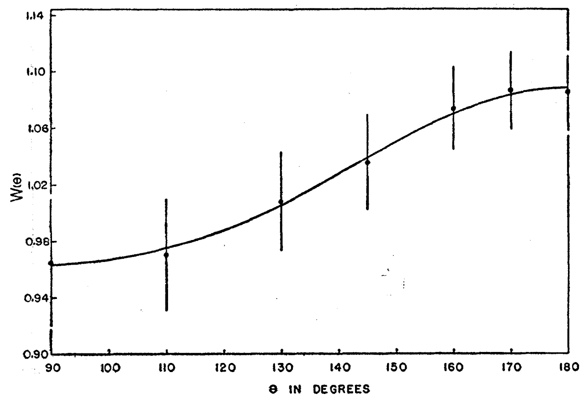

FIG. 4. Directional correlation of the 940–885 kev gamma-ray cascade.

kev level in Cd^{110} must be one of 5, 6, or 7 units. The 530-kev beta component has an allowed shape but a log(ft) value between 7 and 8, suggestive of a first forbidden transition. Consequently, the spin of the 2490-kev level in Cd^{110} is restricted to one of the following values: 4, 5, 6, 7, 8. The last two possibilities can be excluded immediately since the 940–885 kev cascade leads from this level to the first excited 2^+ state at 656 kev, and both gamma rays are intense.

The spin sequences for the cascades studied can now be written down in the form $I_A \rightarrow I \rightarrow I_B$, as follows:

$$1385\text{–}\ 885\ \text{kev}: 5, 6, 7 \rightarrow I(1540\text{-kev level}) \rightarrow 2, \quad (1\text{-}1)$$

$$760\text{–}1510\ \text{kev}: 5, 6, 7 \rightarrow I(2170\text{-kev level}) \rightarrow 2, \quad (2\text{-}2)$$

$$940\text{–}\ 885\ \text{kev}: 4, 5, 6 \rightarrow I(1540\text{-kev level}) \rightarrow 2. \quad (3\text{-}3)$$

The first two cascades have the 2935-kev level in common, while the first and third have the 1540-kev level in common. In seeking suitable values for the spin of the intermediate state in each cascade, radiations of multipole order higher than quadrupole have been excluded. This restriction is consistent with the fact that all the gamma rays involved are relatively intense, and that no state in Cd^{110} has a half-life greater than 6×10^{-10} sec.

The most reasonable values of I for cascades (1-1) and (2-2) are 3 and 4. The sequence $6(Q)4(Q)2$ gives positive values for A_2 and A_4 and can be discarded. A spin of 7 for the 2935-kev level is excluded since this would lead to octupole radiative transitions, as would the sequence $6(O)3(D,Q)2$. The remaining possibilities, $5(D,Q)4(Q)2$ and $5(Q)3(D,Q)2$, give negative values for A_2 and A_4 as required.

Assuming that the spin of the 2490-kev level is either 4 or 6, the sequences $4(D,Q)4(Q)2$ and $6(Q)4(Q)2$ are the most satisfactory ones for the 940–885-kev cascade. The sequences $4(D,Q)3(D,Q)2$ and $5(Q)3(D,Q)2$ must be rejected since a spin of 3 units for the level at 1540 kev gives negative coefficients A_2 and A_4 for (1-1). The sequence $5(D,Q)4(Q)2$ must also be discarded because it gives coefficients which disagree with the experimental values as to sign.

The presence of radiative transitions involving dipole-quadrupole mixtures leads to the introduction into the analysis of a new parameter δ, the mixing ratio, which is defined as the ratio of the reduced matrix element of the quadrupole transition to the reduced matrix element of the dipole transition.[17] δ is real but can be positive or negative, the sign determining the relative phase of the reduced matrix elements. δ^2 is the ratio of the quadrupole intensity to the dipole intensity in a mixed transition. The coefficients A_2 and A_4 can be expressed as functions of the mixing ratio. For spin sequences involving dipole-quadrupole mixtures, these coefficients are quadratic functions of δ. Following a suggestion by Coleman,[18] the spin sequence associated with a particular measured correlation function was determined by plotting A_4 against A_2 using δ as a parameter. For a dipole-quadrupole mixture, the A_4 *vs* A_2 curves are ellipses. To facilitate comparison of theory and experiment, the experimental results for a single cascade are plotted as a point in the "A_2–A_4 plane." If the cascade studied has been free of interference effects, the experimental point should lie on or near that ellipse which corresponds to the correct spin assignment for the

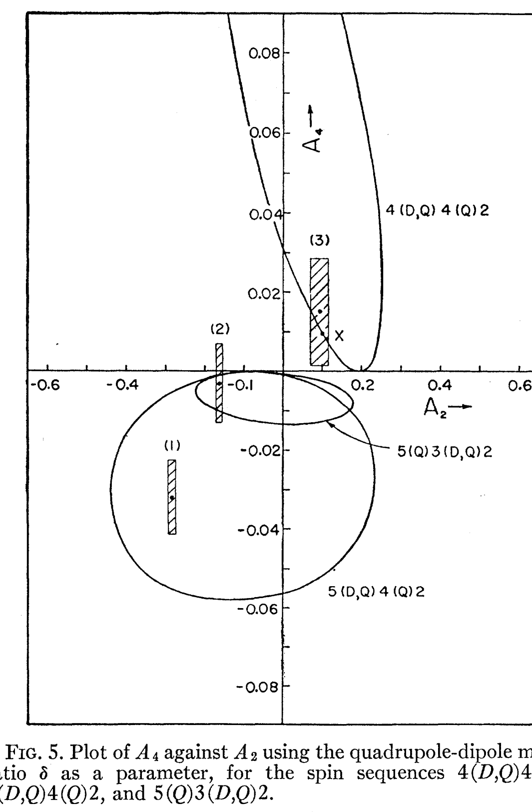

FIG. 5. Plot of A_4 against A_2 using the quadrupole-dipole mixing ratio δ as a parameter, for the spin sequences $4(D,Q)4(Q)2$, $5(D,Q)4(Q)2$, and $5(Q)3(D,Q)2$.

[17] H. Frauenfelder, in *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1955), Chap. XIX.

[18] C. F. Coleman, Nuclear Phys. 5, 495 (1958).

levels concerned. The results for the three cascades studied in Cd^{110} are shown as points in Fig. 5, together with the ellipses for the $5(D,Q)4(Q)2$, $5(Q)3(D,Q)2$ and $4(D,Q)4(Q)2$ spin sequences. The width of the rectangle drawn about each experimental point is twice the experimental error in A_2, the height twice the error in A_4.

The location of the experimental point for cascade (1-1) confirms the possibility of interference by the 760–1510–656 kev cascade mentioned earlier. However the magnitude of the interference was estimated to be not greater than 5%. The graphical display of the results in Fig. 5 over-emphasizes the interference, since A_4 is very sensitive to small perturbing effects. The 885-kev gamma ray is characterized as pure quadrupole in agreement with Bleuler *et al.*[19] and the 1385-kev transition as a dipole-quadrupole mixture. The mixing ratio in this case is not well defined due to the interference, but the value of δ giving the best fit to the experimental data is $+0.366$. The correlation function for this δ is $W(\theta)=1-0.2975P_2(\cos\theta)-0.0068P_4(\cos\theta)$, corresponding to a transition which is 12% quadrupole, 88% dipole.

The experimental result for the 760–1510 kev cascade is in good agreement with either the $5(Q)3(D,Q)2$ or $5(D,Q)4(Q)2$ spin sequence. The latter choice gives the sequence $4(Q)2(Q)0$ for the 1510–656 kev cascade, which is quite in keeping with the general properties of even-even nuclei. However, for this sequence, the 1510-kev gamma ray would be pure quadrupole and the 760-kev gamma ray a dipole-quadrupole mixture. Both assignments are in disagreement with the observed conversion coefficients for the radiations.[12] (Knipper[8] suggests that both the 1510- and 760-kev radiations are multipole mixtures and he sets upper and lower limits on the mixing ratio for each.)

The spin sequence $5(Q)3(D,Q)2$, on the other hand predicts a 760-kev gamma ray which is pure quadrupole and a 1510-kev gamma ray which is a dipole-quadrupole mixture. In view of the good agreement with the conversion coefficient measurements in this case, a spin of 3 was assigned to the 2170-kev level. The choice leads to a quadrupole intensity for the 1510-kev transition of about 8.3%.

The interpretation of the experimental results for the 940–885 kev cascade is more straightforward. A $5(D,Q)4(Q)2$ spin sequence gives correlation coefficients in complete disagreement with experiment. However, both the $6(Q)4(Q)2$ sequence, the coefficients of which are indicated by the letter X in Fig. 5, and the $4(D,Q)4(Q)2$ sequence give satisfactory coefficients. The proximity of the experimental point to the $4(D,Q)4(Q)2$ ellipse makes a unique spin assignment difficult. The first sequence implies that both transitions are pure quadrupole. If the second assignment is the correct one, the best value of δ for the mixed transition is -0.272, which gives a quadrupole intensity of 7.4%.

[19] Bleuler, Blue, Chowdarry, Johnson, and Tendam, Phys. Rev. **90**, 464 (1953).

The parities of the nuclear states studied during this investigation can only be inferred. If the 89- and 530-kev beta transitions are of a different degree of forbiddenness, the 2935- and 2490-kev levels in Cd^{110} should have opposite parity. The shell model predicts that the last proton and neutron in Ag^{110} occupy the $g_{9/2}$ and $g_{7/2}$ levels,[20] respectively, a prediction which is certainly consistent with a spin of 1^+ for the ground state. The high spin of Ag^{110m} can be accounted for by Nordheim's weak rule if the last proton is in a $g_{9/2}$ level, the last neutron in a $d_{5/2}$ level.[2] This configuration fixes the parity of the isomeric state as even, and the multipolarity of the 116-kev gamma ray as $M5$. This classification of the isomeric transition is a reasonable one since Ag^{110m} has always been somewhat of an anomaly in the $M4$ group of isomeric transitions.[21] In addition, it determines the parities of the levels at 2935 and 2490 kev in Cd^{110}. The former must have even parity, the latter odd parity. As a consequence, the 940-kev gamma ray must be either pure $M2$ or an $E1+M2$ mixture depending on whether the spin of the 2490-kev level is 6 or 4 units. Both possibilities conflict with the measured K-conversion coefficient[12] for this gamma ray, which agrees very well with the theoretical value for pure $E2$ radiation.

An alternative approach is to start with the shell-model predictions for Ag^{110m} and the measured multipolarity of the 940-kev gamma ray. This procedure immediately fixes the spin of the 2490-kev level as 6 units, and its parity as even. All the gamma rays involved in the present directional correlation measurements must then be either pure $E2$, or $M1+E2$ mixtures. The 530-kev beta component is probably an allowed transition hindered by the additional selection rules associated with the beta decay of deformed nuclei.[22,23] Several examples of beta transitions which are hindered by factors of 10 or more have appeared in the literature.[24–26] Since the level scheme of Cd^{114} has been shown to exhibit many collective vibrational properties,[27] the similarities between the level schemes of Cd^{110} and Cd^{114} suggest that Cd^{110} is also a deformed nucleus, and that hindered beta transitions from Ag^{110m} are possible.

The parities of the levels at 2170 and 1540 kev must also be even, since the multipolarities of the 760 and 885-kev gamma rays have been determined.[12]

The results of the present investigation are summarized in the simplified decay scheme for Ag^{110m} shown in Fig. 6. Additional details of the scheme are available

[20] M. Goeppert-Mayer, in *Beta- and Gamma-Ray Spectroscopy* (Interscience Publishers Inc., New York, 1955), Chap. 16, Part I.
[21] M. Goldhaber and A. W. Sunyar, in *Beta- and Gamma-Ray Spectroscopy* (Interscience Publishers, Inc., 1955), Chap. 16, Part II.
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[24] D. M. Chase and L. Wilets, Phys. Rev. **101**, 1038 (1956).
[25] J. M. Hollander, Phys. Rev. **105**, 1518 (1957).
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[27] H. Morinaga, Phys. Rev. **103**, 503 (1956).

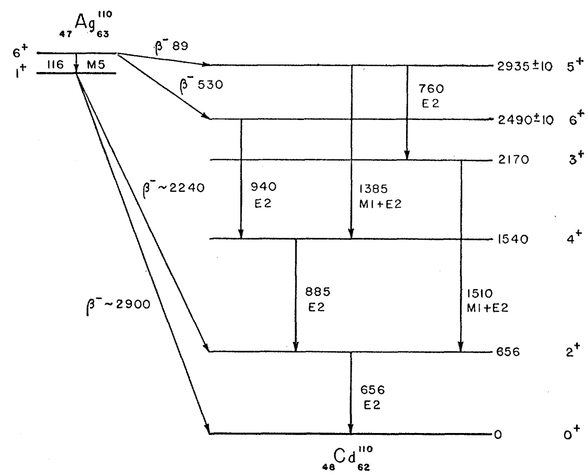

FIG. 6. Simplified decay scheme for Ag^{110m} showing those gamma-ray cascades which were used in the directional correlation studies. All energies are in kev.

in reference 6. Spins and parities consistent with the directional correlation measurements are indicated. Two well-established levels are not shown: a 2^+ level at 1480 kev and a level at 2220 kev of unknown spin. The 1385–885 kev cascade has the spin assignment $5^+(M1+E2)4^+(E2)2^+$, the 760–1510 kev cascade $5^+(E2)3^+(M1+E2)2^+$, and the 940–885 kev cascade $6^+(E2)4^+(E2)2^+$. The spin of the first excited state and the multipolarity of the 656-kev gamma ray have been determined from Coulomb excitation experiments with Cd^{110}.[28]

ACKNOWLEDGMENTS

The authors wish to thank Dr. D. Paul, Royal Military College, Kingston for his search for isomeric states in Cd^{110}, and Dr. P. Stelson, Oak Ridge National Laboratory for communicating his results on Cd^{110} prior to publication.

This investigation has been supported financially by the National Research Council of Canada, the Atomic Energy Control Board, and Queen's University.

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PHYSICAL REVIEW VOLUME 114, NUMBER 1 APRIL 1, 1959

Light-Particle Spectra from the Nitrogen Bombardment of Oxygen

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(Received November 10, 1958)

Energy spectra and angular distributions were measured for protons and α particles resulting from the nitrogen bombardment of oxygen. It was found that the angular distributions of protons are reasonably isotropic whereas α particles are peaked in the forward direction. The energy distributions at various angles were compared with the predictions of a simple level density formula $w=C\exp[2(aE^*)^{\frac{1}{2}}]$. The constant a was found to be $a=2.5\pm0.2$ from proton spectra, $a=1.3\pm0.2$ from α-particle spectra at all angles measured. The energy spectrum of deuterons was measured at 15 deg and a value of $a=1.8\pm0.3$ was found. Unexplained structure was observed in the spectrum of α particles emitted at zero degrees. After correction for the phase space available and the barrier penetration, it was found that α particles are emitted on the order of ten times more copiously than protons, while deuterons are about half as abundant as protons.

INTRODUCTION

HEAVY-ION-INDUCED nuclear reactions at the energies available at this Laboratory are generally characterized by slow-moving incident particles, high energies of excitation due largely to the mass defects of the nuclei involved, and a variety of emitted particles. We concern ourselves here with protons, deuterons, and α particles which are produced from the nitrogen-oxygen reaction. The energy spectra of these particles, as well as their angular distribution in the forward hemisphere are reported here. The results are compared with predictions of a statistical evaporation process from a compound nucleus.

Previous work at this Laboratory has been concerned with energy spectra of light particles from lithium,[1] beryllium,[2] carbon,[3] nitrogen,[3] oxygen,[3] and aluminum[4] targets. In the last case, angular distributions of the emitted particles were also investigated. The present work is an extension of the last-cited reference, and is similar to it except that oxygen was used as a target instead of aluminum.

EXPERIMENTAL METHOD

Thin oxygen targets were prepared by heating clean copper foil, approximately 5 mg/cm^2 thick, in a furnace

* Operated for the U.S.A.E.C. by Union Carbide Corporation.

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