Photoproduction of a 100-μsec Isomer and its Tentative Assignment to Hg^{201}†

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The photoproduction of a 100±6-μsec isomer from a natural Hg target was studied as a function of bremsstrahlung energy by detecting the 533±7 keV gamma ray which dominates the decay. The isomer is produced mainly by a (γ,n) process which has an apparent threshold of 11.3±0.3 MeV and an integrated cross section of 33 MeV mb if the 30% isotope Hg^{202} is the parent. In the energy range from 9 to 12 MeV, the isomer is probably produced by a (γ,γ') process.

The tentative isotopic assignment is strengthened by the presence of what is apparently the same decay gamma ray in the 22-min Au radioactivity which is usually assigned to Au^{201}. Prompt beta-gamma coincidences were observed for Au^{199} and Au^{200} but no prompt coincidences were found for Au^{201}. The Au^{201} activity has a half-life of 22±3 min and a 530±5-keV gamma ray.

I. INTRODUCTION

THE experiment described in this paper was a continuation of the earlier studies at the University of Illinois[1,2] in which short-lived, photoproduced isomers were investigated between the successive 1-μsec yield pulses which are generated 180 times each second by the 25-MeV betatron. Hg was chosen as a target because the earlier studies had indicated the possible existence[3] of the isomer we found.

Once we had definitely established the existence of the isomer, we concentrated on trying to assign it unambiguously to a specific isotope. The main reason for this emphasis on assignment was that there had been considerable attention given to the search[4] for an isomer in Hg^{201} because the systematics of isomeric levels seemed to predict a long-lived isomer. When additional evidence accumulated about the energy levels in nuclei somewhat below Pb in the periodic table, the assignment of isomers to the odd-A isotopes of Hg took on added significance.[5] The detailed study of the levels of Hg^{201} reached in the radioactive decay of Tl^{201} had shown complexities[5,6] which also enhanced the interest in Hg isomers.

The determination of the lifetime of this isomer and the energy of a decay gamma ray is described in Sec. II. The dependence of the photoproduction on the energy of the incoming bremsstrahlung spectrum is described in Sec. III. This energy dependence, coupled with the systematics of the photoproduction of isomers,[2] points strongly to the assignment of the 100-μsec isomer to Hg^{201}. In Sec. IV, a description is given of a preliminary study of the Au fraction chemically separated from a photoirradiated Hg sample. A gamma ray of about the correct energy to be the same one involved in the decay of the 100-μsec isomer had been reported[7] to be associated with the decay of a 26-min activity, assigned[7,8] to Au^{201}. Our preliminary results which include both energy and coincidence measurements are consistent with the presence of the 533-keV gamma ray associated with a 22±3-min Au activity. Furthermore, this gamma ray is not in prompt coincidence with the beta ray that precedes it.

Our experiments were performed in 1957–1958 but we delayed publishing our results in the hope that we could study the isomer in more detail. A more intense photon beam or better detectors would have made it possible to obtain information about the x rays or possible lower energy gamma rays. In addition, a more intense (or higher energy) photon beam could produce Au sources more suitable for the study of the decay of Au^{201} or other Au activities. Inasmuch as we have not been able to return to this investigation, and because there are now several laboratories with better facilities for this interesting study, we are publishing the results we obtained.

The isomer discussed in this paper was observed independently,[9] and the reported energy and half-life values will be compared to our results at the appropriate places below. If our tentative assignment of the 100-μsec activity to Hg^{201} proves correct, it would seem reasonable to assign the additional[9] 21-μsec 333-keV isomer to Hg^{203}.

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II. ENERGY AND LIFETIME DETERMINATION

The experimental setup was essentially the same as that used previously at the University of Illinois.[2] The collimated bremsstrahlung beam was somewhat less than 2 in. in diam at the Hg sample which was about 11 ft from the bremsstrahlung target in the betatron. The front face of a $1\frac{3}{4}$-in.-diam×2-in.-long NaI scintillation detector was somewhat less than 2 in from the center of the beam. The crystal axis was perpendicular to the beam axis, and the sample was tilted to make a 45° angle with both axes.

A. Energy Determination

The principal change from the previously used electronics[1,2] was that a 100-channel analyzer was used instead of the grey-wedge analyzer. Although the energy determination was simplified by the availability of the 100-channel analyzer, the limiting factor was still the dependence of the system gain on the intensity of radiation reaching the NaI. Strong sources of Sn^{113} (392 keV), Na^{22} (511 keV), and Cs^{137} (662 keV) were used to calibrate the energy scale with and without bremsstrahlung striking the target. These sources were strong enough to affect the system gain if they were too close to the NaI crystal.

Seven independent energy determinations were made using a thick Hg sample. Each measurement involved an independent calibration; each calibration measured the intensity dependent gain shifts. (The gain shifts were usually about 2 or 3% and never exceeded 5%; with care, it was possible to obtain calibrations which applied to the conditions under which the energy of the unknown Hg line were measured.) All of the seven determinations can be represented by the energy 533±7 keV. For all of these energy measurements, photons were accepted in a 300-μsec interval beginning 50 μsec after the bremsstrahlung pulse.

The gamma-ray energy resolution, which was about 16%, was much poorer than that used in obtaining the value 515±12 keV.[9] However, our resolution did not limit the precision of our energy measurement. We are rather confident that the energy of the line is well above 515 keV because even with our poor resolution, we had no trouble distinguishing the Hg gamma ray from the 511-keV annihilation gamma ray obtained from a Na^{22} source. The reported possible 580-keV line, presumably associated with a 21-μsec isomer,[9] would have been much too weak for us to see; it certainly would not have affected our energy determination.

The very thick target used during the energy and lifetime measurements discriminated strongly against lower energy gamma rays. The fact that the 217-keV gamma ray reported[9] to be present in the decay of the same isomer was not evident does not set a significant limit on its intensity. However, considerable data were also obtained with a target which had 11.8 g/cm² of Hg perpendicular to the beam during the measurements of the energy dependence. When corrections are made for self-absorption in this target and for the higher detection efficiency of the NaI for lower energy gamma rays, the over-all efficiency for detecting a 217-keV gamma ray would have been about 54% of the efficiency of detecting the 533-keV gamma ray. After the 217-keV gamma ray had been reported, we re-examined our data and found an increased counting rate which could correspond to a gamma ray at an energy of about 230 keV. Unfortunately, we had not examined this energy region of the spectrum sufficiently to be sure of possible backscattering or background contributions. Our data would be consistent with a 217-keV gamma ray provided that its intensity was less than one-half of the intensity of the 533-keV gamma ray. This lower intensity also seems consistent with the original report of the 217-keV gamma ray, which was much more clearly evident when a 2.5-g/cm² sample was used.[9]

During the course of the precise energy measurements, the energies of the gamma rays associated with the 62 μsec isomer[1,2] in Tl were determined. The values we obtained (426±6 keV and 694±6 keV) are in good agreement with the values (419±5 keV and 703±10 keV) previously reported.[2]

B. Lifetime Determination

The lifetime of the isomeric state in Hg was measured relatively precisely on five separate occasions. Each measurement consisted of setting a single-channel pulse-height analyzer on the 533-keV photopeak, and recording the time distribution of these photopeak pulses. A five-channel time analyzer was used in which each channel included a 75-μsec interval. For each lifetime determination the beginning of the first time channel was set first at 50 μsec and then at 350 μsec so that data were obtained from 50 to 725 μsec. Two types of background were subtracted from these data. The largest background was due to long-lived radioactivities in both the Hg sample and the NaI crystal. This background could be determined easily by investigating the counting rate in the accepted energy interval with very large delays. A small correction was also made for the time-dependent background produced by slow neutrons. This background was estimated by measuring as a function of delay the counting rate for pulses somewhat more energetic than the 533 keV photopeak. The measured half-life was 100±6 μsec which is in reasonable agreement with the value of 92±3 μsec reported by Krehbiel and Meyer-Berkhout.[9] (The slight discrepancy is almost surely due to differences in background subtraction.)

III. ENERGY DEPENDENCE OF PHOTOPRODUCTION AND INTEGRATED CROSS SECTION

A. General Energy Dependence of Yield

The energy dependence of the photoproduction of the isomer was determined by making measurements at

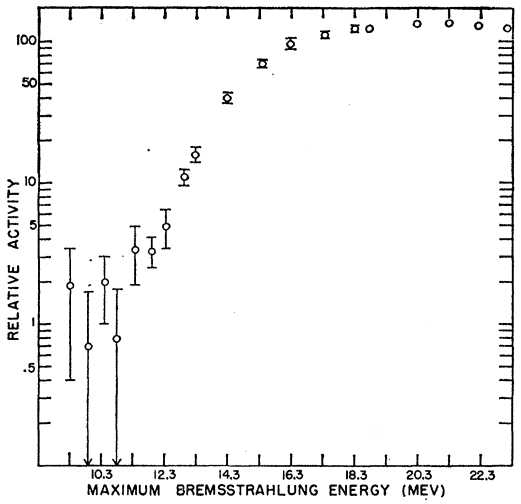

FIG. 1. Activation curve of 100-μsec Hg isomer. The ordinate gives the relative amount of 100-μsec isomer per unit ionization produced in the ionization chamber monitor. If the isomer is in Hg^{201}, the ordinate is approximately 4.1 times the energy-integrated cross section in MeV-mb.

19 different values of the peak energy of the bremsstrahlung spectrum. At each energy, a complete pulse height distribution was obtained for the gamma rays which reached the detector between 40 and 180 μsec after each yield pulse. In addition, the long-lived background was measured after each run, and an estimate was made of contributions due to slow neutrons. The activity assigned to the 100-μsec isomer was obtained by summing the counts above background in the region of the 533-keV photopeak. The energy dependence of the relative activity produced per unit monitor reading is shown in Table I and plotted in Fig. 1. The data shown are the averages of at least two quite independent measurements at each energy; many of the points were measured in three or more separate runs. The results from the separate runs showed that the data were quite reproducible.

TABLE I. Relative yield of 100-μsec isomer as a function of peak bremsstrahlung energy.

Peak energy (MeV)	Relative[a] yield/unit monitor
9.35	0.46±0.37
9.90	0.17±0.24
10.40	0.49±0.24
10.80	0.20±0.24
11.35	0.83±0.37
11.90	0.81±0.20
12.35	1.22±0.37
12.90	2.74±0.37
13.30	3.9 ±0.5
14.30	9.8 ±0.7
15.40	17.0 ±0.7
16.30	23.5 ±1.7
17.40	27.4 ±1.2
18.35	30.6 ±1.0
18.80	30.3 ±1.2
20.30	33.0 ±1.2
21.30	33.0 ±1.0
22.20	31.8 ±1.0
23.20	30.6 ±1.0

[a] The values have been normalized to correspond approximately to the energy integrated cross section in MeV mb.

At all energies above 12 MeV, the gamma-ray pulse-height distributions showed an obvious 533-keV photopeak. However, at the lower energies, particularly below 10.5 MeV, the net counting rate above background was too small and had statistical uncertainties that were too large to define an unambiguous photopeak. These uncertainties persisted despite runs which were more than 24 h long. It is therefore conceivable that the activity observed below 11 MeV was due to some unidentified background. However, all tests, including some made with Tl targets which should have produced equivalent slow neutron yields, were consistent with there being genuine yield of the 100-μsec isomer down to 9.3 MeV.

B. Integrated Cross Section

Although the absolute value of the yield was not measured directly, a relative measurement was made by re-examining the yields of the 585- and 62-μsec isomers in Tl. If the reported value[2] of the energy integrated cross section (up to about 20 MeV) of the 585-μsec isomer in Tl^{202} is accepted as 37 MeV-mb, the integrated cross section for the 100-μsec isomer is within 10% of 33 MeV-mb provided this isomer results from a (γ,n) reaction on Hg^{202}, and provided a 533-keV gamma ray is emitted each time the isomer is formed. The values given in Table I have been normalized to correspond to the approximate values of the integrated cross section (in MeV mb) in accordance with the above assumptions. (Of course, additional corrections would be needed to get exact integrated cross sections because the measured yield would be directly proportional to the integrated cross section only if the number of photons of energy E in the spectrum had an exact $1/E$ energy dependence.)

C. Apparent Threshold

The energy dependence between 11.3 MeV and 14.3 MeV implies a quasi-threshold of 11.3±0.3 MeV for the photoproduction of the 100-μsec isomer by a (γ,n) process. The fact that this apparent threshold is more than several MeV above the true (γ,n) threshold for any Hg isotope fits into the pattern established by both experiments[1,2,10] and theory[11] for the photoproduction of a state which differs markedly in spin from that of the parent nucleus. This particularly large energy difference between the actual threshold and the apparent threshold indicates that producing the isomeric level involves a very large spin change. It is difficult to make

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quantitative estimates because both the emitted neutrons and the gamma rays which follow neutron emission can carry away angular momentum. However, the difference between the quasi-threshold and the actual threshold is probably a semiquantitative measure of the spin change. It is therefore probably noteworthy that the quasi-threshold excess for the activation of Tl isomers[2] (which involve spin changes[5] of 13/2) are quite similar to the quasi-threshold excess for the production of the 100-μsec Hg isomer. A further indication of corresponding spin changes for the photoproduction of the 100-μsec Hg and the Tl isomers is the near equality of the total energy-integrated cross sections, mentioned above.

D. Possible Assignments of Isomer

The fact that the 100-μsec isomer is formed in a (γ,n) reaction restricts its assignment either to one of the two even isotopes Hg^{198} or Hg^{200} or to one of the four odd isotopes Hg^{197}, Hg^{199}, Hg^{201}, and Hg^{203}. The even isotopes can probably be excluded because the known level structures and spin sequences of even-even nuclei are inconsistent with the existence of 100-μsec isomers. The possibilities can be restricted further because there are well-known longer-lived isomers in both Hg^{197} and Hg^{199}. These isomers already account for levels with spin-parity 13/2+, and higher energy states of comparable spin would decay to these known isomeric states relatively quickly. Thus, the two most reasonable assignments for the 100-μsec isomer on the basis of the data discussed above would be to the heretofore unaccounted for 13/2+ states in either Hg^{201} or Hg^{203}. If one accepts the apparent yield of the 100-μsec isomer below 11 MeV as positive evidence for (γ,γ') production, its assignment could be made uniquely to Hg^{201}.

The above considerations and the tentative assignment of the isomer to Hg^{201} led naturally to an attempt to see whether existing evidence about levels in Hg^{201} could be correlated with the observations we had made on the 100-μsec isomer. Our experimental setup and target thickness were not appropriate for detecting the low-energy gamma rays associated with the levels of Hg^{201} reached in the decay of Tl^{201}. However, Krehbiel and Meyer-Berkhout would probably have seen at least the 133- and 167-keV gamma rays if they were present.[9] Inasmuch as there was no correlation between the observed 100-μsec isomer and the decay of Tl^{201}, we investigated the decay of Au^{201}.

IV. CHEMICALLY SEPARATED Au FRACTION

On two separate occasions, Au was separated chemically[12] from Hg which had been irradiated as a chloride for 25 min in a 22-MeV bremsstrahlung beam. The photon spectra of these two Au samples were studied as a function of time for about 80 min. The discriminator on the electron side of the coincidence circuit was set to accept quite low-energy electrons for the measurements taken with one source while a higher discriminator bias was used with the other Au source.

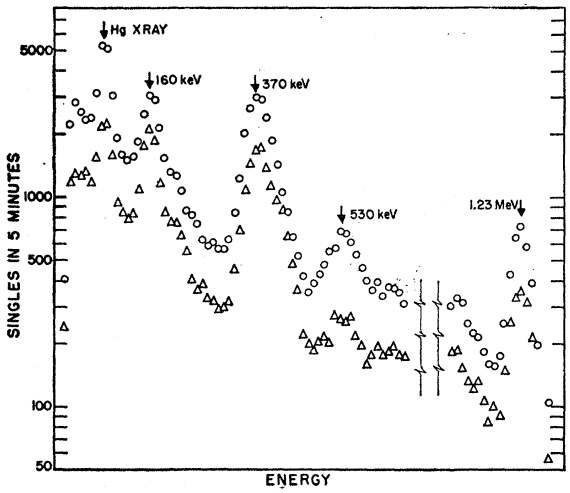

FIG. 2. Photon energy spectrum of Au fraction. Two spectra are shown taken about 43 min apart. The first curve (circles) clearly shows the 530-keV gamma ray which decays with a 22-min half-life. The second curve (triangles) shows that the 160-keV gamma ray has a much longer half-life than the 45 min corresponding to the 370-keV and 1.23-MeV gamma rays.

When these experiments were performed, they were considered as preliminary. We were so convinced that we would repeat and improve these measurements that we did not bother to measure the longer lived activities carefully after the short-lived activities decayed. We also neglected to calibrate the discriminator on the electron side of the coincidence circuit. However, despite these gaps in the data, the results given below are meaningful and interpretable.

A. Energy and Lifetime Measurements

The gamma-ray spectrum contained dominant peaks corresponding to Hg x rays and to gamma rays with energies of 160 keV, 370 keV, 530 keV, and somewhat above 1 MeV. The scintillation spectrometer had been calibrated below 662 keV, and was accurately linear at lower energies. However, there were saturation effects in the amplifier at higher energies. The higher energy part of the spectrum was not studied carefully because the 533-keV gamma ray was the main object of the measurements. Two typical spectra taken 43 min apart are shown in Fig. 2.

The results of the energy and lifetime measurements are summarized in rows 1 to 3 and 6 of Table II. The 160-, 370-, and 530-keV gamma rays whose energies were determined to ± 5 keV had dominant, clearly resolved photopeaks. The gamma ray above 1 MeV, which was also clearly resolved, had a very large energy uncertainty due to the saturation effects mentioned

[12] We are indebted to Dr. Palmer Dyal who performed the chemical separations.

TABLE II. Summary of data on Au fraction.

1. Gamma-ray energy (keV)	160	370	400	530	1100
2. Error in energy (keV)	5	5	25	5	200
3. Measured half-life (min)	Long[a]	48±5	Long	22±3	43±5
4. Probably Au Mass No.	199	200	198	201	200
5. Previously reported half-life[b] (min)	4500	48	3900	26	48
6. Relative counts in photopeak about 35 min after 25-min bombardment	3.7	10	2.4	1.0	2.3
7. Assumed fraction of decay[b]	0.77	0.24	1.0	1.0	0.24
8. Relative (γ,p) integrated cross section	0.75	0.5	1.0	0.01	0.5
9. Relative coincidence rate per detected gamma ray	Accepting all betas				
	0.8	1.0	1.0	<0.3	0.9
10.	Rejecting low betas				
	<0.03	0.3	0.2	<0.04	<0.04

[a] Most of the activity producing the 160-keV gamma ray was long-lived but there may have been some shorter-lived gamma rays in or near the 160-keV photopeak.
[b] See references 14 and 15.

above. It was assumed to be the 1.23-MeV gamma ray previously reported[7,13] to be emitted by 48-min Au^{200}.

The gamma ray listed as 400 keV was never resolved from the stronger 370-keV gamma ray. However, as the source aged during the 80 min of observation, the high-energy side of the 370-keV gamma ray began to develop unmistakable structure. This is beginning to be visible in the lower spectrum of Fig. 2 but was more pronounced in a later spectrum.

Examination of the standard compilations of radioactivity[14,15] shows that the gamma rays listed in Table II account for all of the expected (γ,p) products from Hg except the very short-lived activities 55-sec Au^{203} and 7-sec Au^{197m}. Furthermore, the only reported[14,15] gamma rays not listed in Table II but expected in the Au fraction are the 208- and 50-keV gamma rays of Au^{199} which would have been too weak to be detected in our experiment. The 217-keV gamma ray reported[9] in the 100-μsec Hg isomer would also have been too weak to stand out from the 370-keV Compton distribution. Similarly, the 133- or 167-keV gamma rays in Hg^{201} would have been too weak to be evident. The observed gamma-ray spectrum could conceivably have had some contamination due to imperfect separation of Au from the much more intensely produced Hg radioactivities. The shortest lived Hg product expected[14,15] is 42 min Hg^{199m} whose main gamma rays (159 keV and 368 keV) could not have been distinguished in energy from expected Au gamma rays. However, the apparent lack of decay of the observed 160-keV gamma ray indicates that little if any Hg contamination was present.

The assignment (shown in row 4 of Table II) of the observed gamma rays to known[13,14] isotopes of Au was made on the basis of energy and lifetime. From the point of view of adding precise energy or lifetime determinations, the only two noteworthy entries in Table II are the energy (530±5 keV) and the half-life (22±3 min) of the activity previously assigned[7,8] to Au^{201}.

Additional data of interest can be obtained by calculating the relative energy-integrated (γ,p) cross sections from the observed intensity of the different gamma rays (shown on row 6 of Table II). These intensities were first corrected for the probability that the assumed Au parent decays by the gamma ray in accordance with the branching ratios[14,15] given in row 7. No corrections were made for internal conversion. In addition, the observed intensities were corrected for the relative abundances of the (γ,p) parents,[14,15] the scintillation detection efficiency, and the different decay constants. The resultant approximate relative energy-integrated cross sections are given on row 8 of Table II. The relative energy-integrated (γ,p) cross sections of Au^{198}, Au^{199}, and Au^{200} are gratifyingly close. (The yield of Au^{198} is somewhat uncertain because the 412-keV gamma ray was never completely resolved.) To the precision of these measurements, the relative energy-integrated (γ,p) cross sections of these three isotopes may have been equal, and were surely within a factor of 2 or 3 of each other. In contrast, the apparent yield of the 530-keV gamma ray is too low by a factor of 50 or 100. This low yield implies that the 530-keV gamma ray is associated with only a small fraction of the (γ,p) process on Hg^{202}. This fraction may be so small either because of a very small probability that the 22-min Au^{201} decays by means of this 530-keV gamma ray or because only a small fraction of the (γ,p) process on Hg^{202} reaches the 22-min Au^{201} activity.

B. Coincidence Experiments

A different beta-gamma prompt coincidence experiment was performed with each of the two Au sources. In the first experiment, the discriminator on the electron side of the coincidence circuit was set to accept quite low energy electrons. A typical coincidence spectrum obtained in 5 min is shown in Fig. 3. (The gain is slightly different from that in Fig. 2 or Fig. 4). The resultant relative coincidence rate per detected gamma

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[14] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[15] *Nuclear Data Sheets*, published by The National Academy of Sciences, National Research Council (U. S. Government Printing Office, Washington, D. C.).

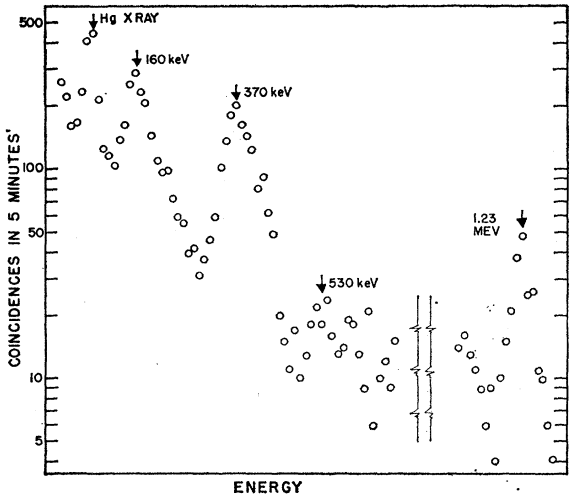

FIG. 3. Spectrum of photons in prompt coincidence with electrons. Coincidences are obvious for Hg x rays, and for 160-, 370-, and 1.23-MeV gamma rays. There is also evidence for coincidences corresponding to 410-keV gamma rays. No evidence exists for a coincidence peak due to the 530-keV gamma ray.

ray for this arrangement is shown on row 9 of Table II. (The values given are normalized; the actual maximum coincidence probability per gamma ray was about 0.1.) No evidence was found for prompt beta-gamma coincidences with the 530 keV gamma ray. The upper limit given in Table II is as high as it is because of the poor statistics obtained in the coincidences due to Compton distribution of the 1.23-MeV gamma ray (see Fig. 3). The high relative efficiency for detecting beta-gamma coincidences for the 158-keV gamma rays of Au^{199} indicate that the electron discriminator bias was low enough to accept many of the 300-keV beta rays which lead to this gamma ray. The absence of coincidences involving the 530-keV gamma ray in this case suggests that there are no prompt coincidences. This conclusion coupled with the known 100-μsec half-life of the 533-keV gamma ray suggests strongly that the 530-kev gamma ray in the decay of Au^{201} is delayed. (Several attempts to find delayed coincidences with other Au sources were inconclusive.)

The second coincidence experiment was performed with a higher discriminator bias on the electron side of the coincidence circuit. A spectrum obtained in 10 min is shown in Fig. 4. The results are given on row 10 of Table II; the values given are on the same relative scale as is used in row 9. The higher bias eliminated all indication of prompt coincidences for all but the 370-keV and the 412-keV gamma rays. These coincidence data seem to be the first direct indication that the 367-keV gamma ray of Au^{200} has higher energy beta rays associated with it than does the 1.23-MeV gamma ray. As with the first source, there was no indication of prompt beta-gamma coincidences associated with the 530-keV gamma ray. The absence of 1.23-MeV coincidences made it possible to establish a lower upper limit of 530-keV prompt coincidences, but the exact electron discriminator bias was not measured. (It can be estimated from the fact that the coincidence efficiency for the 367 keV gamma ray and for the 412-keV gamma ray dropped by about a factor of 3. The 412-keV gamma ray almost surely follows a 960-keV beta ray.[14,15] It is not clear what energy beta ray precedes the 367-keV gamma ray in Au^{200} inasmuch as our data imply that the 367-keV and 1.23-MeV gamma rays follow different beta rays.)

C. Conclusions

Both the presence of the 530±5-keV gamma ray and the absence of prompt coincidences make it seem likely that the 22-min Au^{201} decays, at least in part, through the isomeric level of Hg^{201}. However, this conclusion leaves a number of unanswered questions about Au^{201}. If the 22-min Au^{201} is the expected 3/2+ ground state, it would not be surprising that the 530-keV gamma ray accounts for only 1 or 2% of the anticipated Hg^{201} (γ,p) yield; in fact, it would be the strength rather than the weakness of the 530 keV which would merit attention in this case. Why would so large a spin change appear noticeably in a beta decay process? At least a partial answer to this question could be obtained by measuring the relative number of beta rays and 530-keV gamma rays in the 22-min activity.

On the other hand, the 22-min Au^{201} might be due instead to the 11/2- level which is isomeric in many of the odd-mass Au isotopes. This hypothesis would explain why the Hg^{201} isomeric level is populated in the

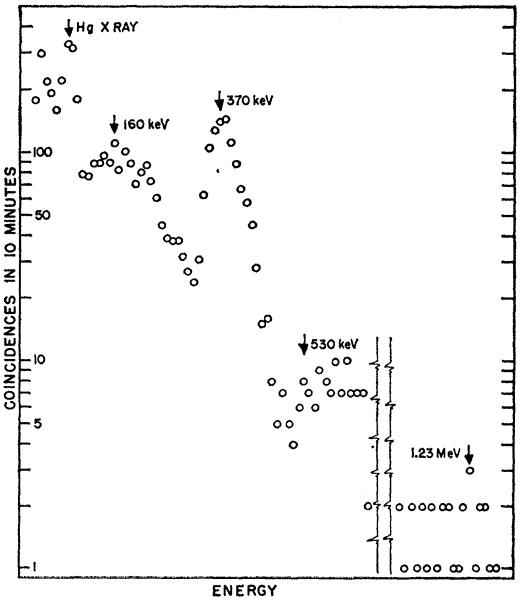

FIG. 4. Spectrum of photons in prompt coincidence with high-energy electrons. Coincidences are obvious for Hg x rays and for 370-keV gamma rays. There is also evidence for coincidences corresponding to 410-keV gamma rays. No evidence exists for coincidence peaks due to the 160-, 530-, or 1.23-MeV gamma rays.

22-min Au decay, but it would leave open the question of the energy and the decay of the expected low-lying 3/2+ state in the same Au isotope.

The incompleteness of the experimental results given above and the unanswered questions call for additional experiments. The decay of 22-min Au^{201} can be studied more precisely and in more detail. In particular, the relative beta intensity and the possible presence of lower energy gamma rays could be found. Furthermore, shorter bombardments and more rapid chemistry might give information about an isomer in Au^{201} analogous to those occurring in the other odd-mass Au isotopes. These investigations would not only give interesting information about Au^{201}, but they would also contribute to knowledge of the puzzling level structure in Hg^{201}.

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(p,n) Cross Sections of V^{51}, Cr^{52}, Cu^{63}, Cu^{65}, Ag^{107}, Ag^{109}, Cd^{111}, Cd^{114}, and La^{139} from 5 to 10.5 MeV*

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(p,n) cross sections were measured by the activation technique in the energy range 5 to 10.5 MeV for the target nuclides V^{51}, Cr^{52}, Cu^{63}, Cu^{65}, Ag^{107}, Ag^{109}, Cd^{111}, Cd^{114}, and La^{139}. Approximate proton reaction cross sections were obtained at energies below the $(p,2n)$ threshold by adding to the (p,n) cross sections the previously reported charged-particle-emission (p,q) cross sections. These results are compared at a few energies with volume absorption and surface absorption optical-model calculations of the proton reaction cross sections.

I. INTRODUCTION

RECENTLY several authors[1–11] have reported on measurements of proton-reaction cross sections at energies equal to or less than 11 MeV. In several of the publications,[1–9] the experimental results have been compared with theoretical-reaction cross sections given by an optical model with parameters obtained from fitting elastic scattering data. Theoretical calculations of the reaction cross sections have assumed both surface and volume absorption.

The experiments measuring the total-reaction cross section are of two basic types. One method (hereafter referred to as method 1) consists of summing all partial-reaction cross sections such as (p,xn), (p,γ) and (p,q) cross sections, where the (p,q) cross section includes all the inelastic charged-particle emission processes. This method neglects the compound-elastic scattering cross section. In a more recently developed method (hereafter referred to as method 2) the reaction cross section is measured by direct attenuation of the incident beam intensity.[9–11]

In the determination of reaction cross sections by method 1, accurate values of the individual cross sections are desired in order to keep the sum of the individual errors to a minimum. The (p,xn) cross sections reported in the literature have been determined by activation measurements and neutron counting. At proton bombarding energies where the $(p,2n)$ threshold is exceeded, the conversion of the neutron counting rate to cross section requires information on the competition between the (p,n) and $(p,2n)$ reactions. Some of the published cross-section values from the neutron counting technique are based on calculated estimates[2]

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