Cr^{49} would favor a ground-state spin assignment of $f_{7/2}$ for V^{49}. On the other hand, Flowers,[14] on the basis of theoretical considerations of nuclei having 23 or 25 odd nucleons, would favor a 5/2, minus-parity state, in analogy with Ti^{47}. The ground level of Ti^{49} has been measured to be in a $f_{7/2}$ state. From the experimental evidence offered above, it is impossible to decide whether the ground state of V^{49} is a 5/2 minus or 7/2 minus state. However, the $\log ft = 6.20$ is consistent with other allowed transitions in this region of mass number where the transitions occur between levels in $f_{7/2}$ states.[15]

The authors wish to express their thanks to Dr. R. J. Glauber and Dr. P. C. Martin of Harvard University for several discussions and for making their results available prior to publication, to Dr. G. M. Temmer of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for providing the irradiated titanium target, and to Mr. A. Schwebel for performing the chemical separation of the vanadium.

[14] B. H. Flowers, Phil. Mag. **45**, 329 (1954).

[15] R. W. King, Revs. Modern Phys. **26**, 327 (1954).

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Inelastic Nuclear Scattering of Photons by Au^{197}†*

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A lower limit of the total inelastic nuclear photon scattering cross section of Au was determined as a function of energy by measuring the yield of the reaction $Au^{197}(\gamma,\gamma')Au^{197m}$ (7.5 sec) as a function of betatron energy. The use of pneumatic transfer and of NaI-counters in good geometry with 16-gram gold disks as samples enabled one to obtain good counting statistics and detailed decay curves at all betatron energies between 4 and 24 Mev. It is found that the cross section falls off steeply as soon as the competition from the (γ,n) reaction becomes possible. The maximum cross section of about 3.5 mb is reached at (7.8 ± 0.2) Mev. This disagrees with earlier work of Cameron and Katz but corresponds qualitatively to the same behavior as exhibited by $In^{115}(\gamma,\gamma')In^{115m}$ in the recent work of Burkhardt *et al.* Our results indicate a second peak of the cross section at about 15 Mev, where the giant resonance has its maximum, in agreement with recent work of Hayward and Fuller on elastic scattering from gold.

These results are compared with the predictions based on the statistical model. It is shown that they can be interpreted most naturally by assuming that below 12 Mev the width for γ emission is of the order of Weisskopf's estimate for Γ_{E2} or Γ_{M1}. Available experimental data on (γ,γ') reactions in other elements are reconsidered in the light of this conclusion.

I. INTRODUCTION

IN recent years, the method by which the Notre Dame group[1,2] excited isomeric states in stable nuclei has found increasing application for the study of (γ,γ') reactions, i.e., of inelastic nuclear photon scattering processes, in the region of the giant resonance in the nuclear absorption of γ rays. In this method, an element having a nuclear isomer and preferably of monoisotopic constitution, is irradiated with γ rays and the resulting isomeric activity is determined. The cross section for this process contributes a lower limit to that for the (γ,γ') reaction because only part of the cascades following γ-ray absorption leads to the isomeric state of which the decay is detected. This fact, as well as the small number of suitable elements, constitutes a severe limitation on the technique. It has, on the other hand, the advantage of considerable experimental simplicity and great sensitivity, making it one of the few tools by which γ-ray absorption below particle emission threshold can be studied conveniently.

Cameron and Katz[3] were the first to employ this technique; they studied the inelastic scattering from gold through the reaction $Au^{197}(\gamma,\gamma')Au^{197m}$ (7.5 sec). Their results indicated that the cross section for this reaction has a single maximum located at the same energy (15 Mev) as the giant resonance peak of gold, as inferred from $Au^{197}(\gamma,n)Au^{196}$. This result appeared surprising in view of the observations in subsequent analogous experiments on $Rh^{103}(\gamma,\gamma')Rh^{103m}$ [4] and $In^{115}(\gamma,\gamma')In^{115m}$.[5] The cross sections for these processes were found to exhibit peaks at lower energies than for gold and far below the respective absorption peaks; though, since the target elements involved are lighter than gold, these absorption peaks lie at higher energies than the absorption peak of Au^{197}. Furthermore, simple

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* A report on this work was presented at the 1955 Mexico City meeting of the American Physical Society; see L. Meyer-Schützmeister and V. L. Telegdi, Phys. Rev. **100**, 961(A) (1955).

[1] Waldman, Collins, Stubblefield, and Goldhaber, Phys. Rev. **55**, 1129 (1939).

[2] M. L. Wiedenbeck, Phys. Rev. **68**, 1 (1945).

[3] A. G. W. Cameron and L. Katz, Phys. Rev. **84**, 608 (1951).

[4] C. S. Rio y Sierra and V. L. Telegdi, Phys. Rev. **90**, 339 (1953). (Hereafter referred to as I.)

[5] G. Goldemberg and L. Katz, Phys. Rev. **90**, 308 (1953).

theoretical arguments based on the statistical model made it plausible that (γ,γ') cross sections ought to fall off sharply above the (γ,n) threshold owing to the competition from $(\gamma,\gamma'n)$ and (γ,n) reactions.

In view of this situation and the admittedly poor statistics on which Cameron and Katz[3] based their conclusions, it was decided to reinvestigate $Au^{197}(\gamma,\gamma')$-Au^{197m}. A technique leading to much better counting statistics was developed and is described in Sec. II. In Sec. III the results obtained with this technique are described and discussed. It is found that $Au^{197}(\gamma,\gamma')$-Au^{197m} exhibits a distinct sharp peak near the (γ,n) threshold and probably a second peak at the energy of the giant resonance. Conclusions based on these results are presented in Sec. IV, where the latter are likewise interpreted in the light of recent related experimental evidence.

II. EXPERIMENTAL PROCEDURE

The original experiments[3] on the reaction $Au^{197}(\gamma,\gamma')$-Au^{197m} were carried out by irradiating very *thin* gold foils and counting the isomeric conversion electrons with a Geiger counter. As these electrons have a maximum range, R, of about 60 mg/cm² and emerge only from an equivalent layer $R/4$ thick, it is obvious that this method is bound to give low specific activities even with very thick samples. Conversely, gold is comparatively transparent to the electromagnetic radiations emitted in the decay of Au^{197m} and these radiations, being of low energy, are detected with high efficiency in NaI(Tl) scintillators of modest dimensions. This observation was the basis for the technique adopted in the experiments described hereafter.

Our counting equipment consisted of two NaI(Tl) crystals of 1 in. diameter and 1 in. height, mounted on DuMont 6292 photomultipliers. These crystals were so arranged coaxially inside a lead shield that the samples, disks of very pure gold of 1 in. diameter and 1.7 mm thickness (3.1 g/cm²), could be sandwiched between them. The center of the sample disk was on the axis of the crystals and it subtended a solid angle of nearly 4π at the crystals. Preamplifiers followed the photomultipliers and their outputs, after adjustment for equal gain, were put in parallel and connected to a conventional linear amplifier, discriminator, and scaler arrangement. In order to obtain a high counting efficiency for the radiations of Au^{197m}, it would in principle be desirable to detect the unconverted γ rays as well as the x-radiation following conversion. For reasons which will be discussed in detail below, the discriminator following the linear amplifier was set so that pulses from the photopeak of the Au K x-radiation were accepted, while the L x-rays were rejected. Most conversion electrons could also be counted with this setting but their contribution was negligible in view of the thickness of the samples used.

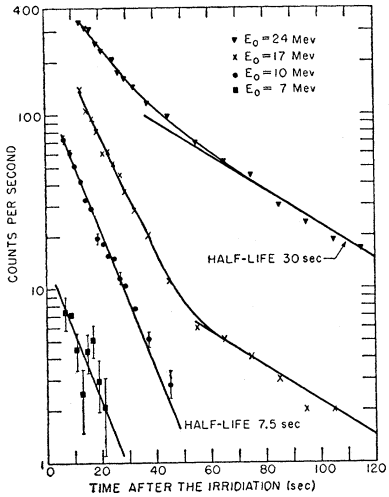

FIG. 1. Decay curves of the gold samples after irradiation at various betatron energies E_0.

The gold samples were irradiated in the γ-ray beam of the Chicago betatron. Immediately after the irradiation, which normally lasted 20 seconds, the sample was pneumatically transferred to the counting equipment within 5 seconds and the counting was started 2 seconds later; this procedure was chosen to maximize the reproducibility of the counting of the 7.5-second Au^{197m} while keeping decay losses low. The sample could be transferred back automatically to its position for irradiation. In order to repeat runs reproducibly, a timer was used which automatically stopped and started the bombardment counting periods in constant but adjustable time intervals. The output of the scaler could optionally be connected to a Brush recorder for the purpose of enabling one to establish the half-life (or half-lives) of the decay activity (or activities).

The instantaneous intensity, I, of the betatron beam was monitored during runs with an "off-beam" ionization chamber. Since it was impractical to maintain a constant intensity during the short bombardments, this chamber was connected to an "activity computer" circuit having a variable time constant. If this time constant was chosen equal to the decay constant λ of the activity induced by the γ-ray beam, this "activity computer" indicated directly the relative yields $[\sim\int_0^T I(t)e^{-\lambda t}dt]$ of the samples bombarded in different runs of duration T. The calibration of the off-beam ionization chamber in terms of "roentgens" [6] was achieved by comparison with a Victoreen thimble imbedded in an 8-cm Lucite cube. In order to gain some confidence in the γ-ray spectrum of the betatron, the yield function for the reaction $Cu^{63}(\gamma,n)Cu^{62}$ was measured up to 24 Mev. The beam used to obtain the data presented in this paper led to a yield curve which is, within our experimental errors, in quantitative agreement with the one obtained by Katz and co-workers.[6]

We measured the yield for the process $Au^{197}(\gamma,\gamma')$

[6] Johns, Katz, Douglas, and Haslam, Phys. Rev. **80**, 1062 (1950).

in 0.5-Mev intervals at all energies between 4 and 24 Mev; the stability in energy of the betatron was of the order of ± 100 kev. The choice of the lowest energy was dictated by the ratio of Au^{197m} activity to background; this ratio was already as low as 1/20 at 4 Mev. The energy range in which the Au^{197m} yield was determined by us can for purposes of discussion be subdivided as follows:

(a) $\hbar\omega \leqslant 8$ Mev [threshold for $Au^{197}(\gamma,n)Au^{196}$]: The only activity to expect is the 7.5-sec Au^{197m}, induced by γ's.

(b) $8 < \hbar\omega \leqslant 15$ Mev [approximate threshold for $Au^{197}(\gamma,2n)Au^{195,195m}$]. In this range one expects, besides a background from the 5.6-day Au^{196}, Au^{197m} excited by both γ's and (n,n') processes due to neutrons produced both inside and outside the gold sample.

(c) $15 < \hbar\omega \leqslant 24$ Mev: In addition to the 7.5-sec Au^{197m} activity induced as in range (b) and the long-lived background, one expects in this range Au^{195} (180-day) and Au^{195m} (30 sec). This latter isomer, the existence of which was established[7] after Cameron and

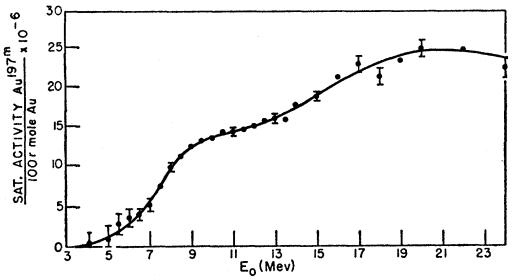

FIG. 2. Absolute yield of Au^{197m} *versus* betatron energy E_0. Errors indicated are statistical.

Katz's[3] work on gold, could be invoked to explain a 30-sec activity observed by these authors.

We first established that in ranges (*a*) and (*b*) Au^{197m} is indeed the sole short-lived activity induced. For this purpose the decay was followed (see Fig. 1) on the Brush recorder, and the energy spectrum measured by means of a multichannel analyzer. The half-life as well as the pulse-height distribution were found to agree with those expected from Au^{197m}; Fig. 1 shows decay curves obtained with irradiations at 7 and 10 Mev. After this verification, an irradiation time of 20 seconds was chosen for all runs below 15 Mev, and the Au^{197m} activity was simply measured by registering the total number of counts during a fixed time interval of 15 seconds, correcting for the long-lived background at runs above 8 Mev.

It was found that a distinct 30-sec component arises, as expected, above 15 Mev; Fig. 1 shows sample decay curves obtained in runs at 17 and 24 Mev. An irradi-

[7] Huber, Joly, Scherrer, and Verster, Helv. Phys. Acta **25**, 621 (1952).

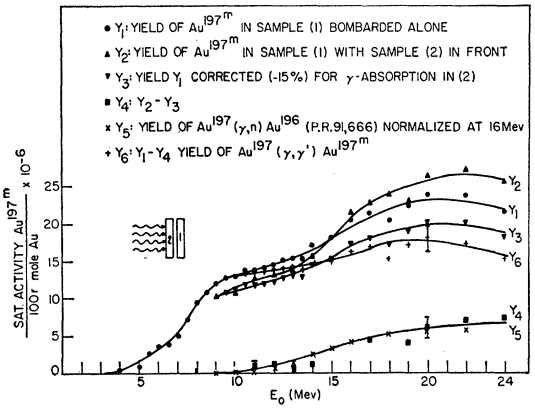

FIG. 3. Summary of various yields used to evaluate the absolute yield of $Au^{197}(\gamma,\gamma')Au^{197m}$.

ation time of 10 seconds was therefore chosen in region (*c*) and the decay was followed during all runs on the Brush recorder. The Au^{197m} activity was then determined by analyzing such decay plots as shown in Fig. 1 in the conventional manner. As it was felt that the yield of Au^{195m} from $Au^{197}(\gamma,2n)$ would be of some interest in view of future comparison with the total $Au^{197}(\gamma,2n)$ yield, special runs with 30 seconds irradiation time were also made and analyzed in an analogous manner.

Figure 2 shows the Au^{197m} yields so obtained for the entire range covered by the present experiments, i.e., 4 to 24 Mev. These yields have already been converted to absolute units by correcting for the finite efficiency of the counting system for the radiations of Au^{197m} (see later discussion). However, they do *not* always correspond to absolute yields for $Au^{197}(\gamma,\gamma')Au^{197m}$, because in regions (*b*) and (*c*) the excitation of Au^{197m} by inelastic scattering of neutrons is also possible, and in particular at energies above 15 Mev the contribution from photoneutrons produced in the gold sample itself is expected to be considerable. In order to obtain a reliable estimate of this effect, another gold disk (2)—of dimensions identical with those of the sample—was put in front of and close to the gold sample proper (1), as schematically indicated in Fig. 3. We found that, in this arrangement, at energies above 15 Mev the yield of Au^{197m} in the sample is higher with than without the front disk (2), although the latter attenuates the incident γ beam to some extent. This attenuation of the γ beam by the front disk was also determined experimentally. At energies below 12 Mev, where the neutron effects are either zero or negligible, this was done by comparing the yields of Au^{197m} with and without the front disk, and at energies above 15 Mev by comparing the yields of Au^{195m} to which neutron effects do not contribute. Within our experimental uncertainties, the attenuation of the γ beam amounted to 15% within the entire energy range of interest. By using these results, the measured yields of Au^{197m} (Fig. 2) could be

corrected for neutron effects as will be discussed in detail in the next section.

To obtain absolute yields such as presented in Fig. 2, we had to determine the detection efficiency of our counting system for the radiations of Au^{197m}. This was done by using a calibrated source of Hg^{203} as an auxiliary standard, making use of the fact that this nuclide decays by β^- emission followed by a single γ transition, the energy (279 kev) and the conversion characteristics of which are very similar to those of the 277-kev transition in Au^{197m}. However, while Hg^{203} involves only this single γ transition, the 277-kev γ transition in Au^{197m} is preceded by a 130-kev transition. In order to equalize the counting efficiencies for Hg^{203} and Au^{197m}, one has thus to suppress the response of the counting system to radiations from the 130-kev transition of Au^{197m} and to the β-rays of Hg^{203}. The conversion characteristics of the 130-kev transition are: 4% unconverted γ rays, 6% K conversion, the rest converted in L and higher shells. By setting the bias of the pulse height discriminator slightly above the L x-ray energy of Au, 90% of the radiations are thus effectively not counted; L and M x-rays are rejected, while the conversion electrons are absorbed by the Al cans (30 mg/cm^2) in which the crystals are enclosed. The detection efficiency for the 130-kev transition is further decreased by the fact that the Au^{197m} activity is distributed throughout the thick (3.1 g/cm^2) gold samples in which the 130-kev γ rays as well as the K x-rays are absorbed more rapidly than the 277-kev γ rays. We estimate that under these conditions the 130-kev transition contributes an uncertainty of 8% to our final value of the absolute efficiency.

In order to correct for the β particles and for the self-absorption in our gold samples, an essentially weightless Hg^{203} source of known strength was spread uniformly over circular area equal to that of the gold samples. This source was either (a) sandwiched between two gold disks or (b) placed behind a single gold disk, the whole being arranged between the two crystals coaxially with them. The counts from each of the two crystals and from both jointly were measured in these geometries. In both geometries the thicknesses of the disks were varied, but in arrangement (a) the sum of their thicknesses was kept equal to that of the actual samples. Measurements in geometry (b) showed that with no absorber on either side of the source, 25% of the counts from Hg^{203} were due to electrons. The counting efficiency for γ rays and K x-rays alone amounted to 23%. Measurements in geometry (a) gave an average counting efficiency of 15% for Au^{197m} distributed uniformly throughout a gold disk of 3.1 g/cm^2, the contribution of conversion electrons being justifiably neglected. When one takes the absorption of the betatron beam in the samples into account, this efficiency is reduced to 14%. For the reasons indicated above, there is an uncertainty of 8% in the absolute magnitude of the counting efficiency so derived; we adopted the figure 15% for the computation of absolute yields.

III. RESULTS AND DISCUSSION

In the preceding section we have described the techniques used to obtain the absolute Au^{197m} yield curve reproduced in Figs. 2 and 3 (curve Y_1). We shall now discuss the cross section extracted from these yield data with reference to Figs. 3 and 4. From the measured Au^{197m} yield, Y_1, indicated in Figs. 3 and 4(b), one obtains by the photon difference method[8] a cross section σ_1 indicated by crosses in Fig. 4(a). This cross section is seen to exhibit two peaks, at 7.5 Mev and 15 Mev, respectively. The first, and smaller, of these is located approximately at the $Au^{197}(\gamma,n)$ threshold and falls off very steeply, while the other one coincides roughly with the maximum in the absorption cross section of Au and is broader. In view both of the presence of neutron-induced Au^{197m} activity above about 12 Mev (see Sec. II) and of the nature of the photon-difference method, the reality of the higher energy peak cannot be accepted readily. The gross yield curve Y_1 has first to be converted to a *true* yield curve for $Au^{197}(\gamma,\gamma')Au^{197m}$.

This conversion was made on the basis of measurements in the 2-disk arrangement mentioned in the previous section. In Fig. 3, Y_2 represents the Au^{197m} yield in a disk (1) with an identical disk (2) placed in front of it. In the region below 12 Mev, where the contributions from $Au^{197}(n,n')Au^{197m}$ is expected to be negligible, Y_1 and Y_2 run parallel, differing only in magnitude owing to beam attenuation in the front disk (2). Assuming this attenuation to be independent of energy, one obtains by applying a constant correction (−15%) to Y_1, the yield curve Y_3. This is the yield curve which one would obtain if the sole effect of the front disk (2) were beam attenuation, and is to be compared with Y_2. Above 13 Mev, Y_2 and Y_3 become more and more divergent, Y_2 always being larger than Y_3; the difference Y_2-Y_3 is plotted (■) as Y_4 in Fig. 3. It is easily seen that Y_4 is not only due to the Au^{197m} yield induced in disk (1) by neutrons originating in disk (2), but indeed corresponds to first order to the Au^{197m} yield induced in disk (1) by the neutrons generated in this disk itself in the absence of disk (2). This is because only half the neutrons emitted by disk (2) impinge on disk (1), while the effective thickness of disk (1) for neutrons generated within it in half its real thickness. The true yield for $Au^{197}(\gamma,\gamma')$, Y_6, is obtained by subtracting Y_4 from Y_1.

Confidence for this method of correction is gained by observing: (a) that the somewhat surprising magnitude

[8] L. Katz and A. G. W. Cameron, Can. J. Phys. **29**, 518 (1951). Extensions of the tables of this paper to lower energies were kindly supplied by Professor Katz. The modification of the bremsstrahlung spectrum as seen by a sample *inside* a Lucite cube, originally taken into account by these authors, was removed by us in accordance with the actual experimental situation.

of this "self-neutron"-induced Au^{197m} yield agrees well with that estimated from the reported $Au^{197}(\gamma,n)$[9] and $Au^{197}(n,n')Au^{197m}$[10] cross sections with reasonable assumptions for the photoneutron spectrum; (b) that the energy dependence of the neutron-induced yield Y_4 is quite similar to that of the $Au^{197}(\gamma,xn)$ yield, indicated by Y_5 in Fig. 3.

Au^{197m} could, of course, also be induced by neutrons produced outside the gold sample. Their contribution should, however, be negligible in comparison to the effect just discussed, in view of the geometry of the experiment (large distance of sample from betatron target and doughnut) and the particularly low (γ,n) threshold of Au. In the less favorable case of Rh, measurements in this laboratory[4] indicated a correction at 6% at 18 Mev.

Accepting Y_6 as the final $Au^{197}(\gamma,\gamma')$ curve, we compute the cross section indicated by σ_6 [see Figs. 4(a), and 4(b)]. This cross section coincides at and below 11 Mev with σ_1, and exhibits again a prominent second peak at about 15 Mev. To check how sensitive the existence of this latter peak is to the correction for neutron-induced yield indicated above, we have computed the yield, Y_0, that would correspond to an assumed $Au^{197}(\gamma,\gamma')Au^{197m}$ cross section σ_0, that is zero above 9 Mev. As is seen by comparing Y_1 and Y_6 in Fig. 4(b), about twice as large a correction as Y_4 would have to be applied to Y_1 to make it agree with this assumption. We believe that such a discrepancy is hard to reconcile with the estimated accuracy of our correction Y_4.

Our final cross section for $Au^{197}(\gamma,\gamma')Au^{197m}$ disagrees with the early work of Cameron and Katz.[3] Fuller and Hayward[11] have studied the *elastic* scattering of γ rays from a number of elements, and in general found two peaks in the cross section, in agreement with the predictions of Ashkin and Bethe.[12] In the work of Fuller and Hayward, only the element investigated here, gold, failed to exhibit a low-energy peak in the vicinity of the (γ,n) threshold, while their high-energy peak agrees in location and approximately also in magnitude with our second peak. The reasons for this apparently singular behavior of gold might well be purely experimental. The low-energy peak reported here is extremely sharp, and it could have been bracketed within the points taken by Fuller and Hayward at rather wide energy intervals. It is to be noticed that the process $In^{115}(\gamma,\gamma')$-In^{115m}, according to recent results of Burkhardt *et al.*,[13]

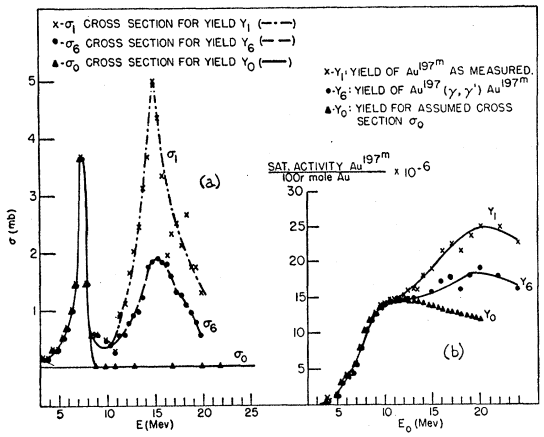

FIG. 4. Comparison of cross sections (a) and yields (b) for Au^{197m} (induced by any process) and for $Au^{197}(\gamma,\gamma')Au^{197m}$.

also exhibits a peak near the (γ,n) threshold that is very narrow and falls off very sharply.

IV. INTERPRETATION AND DISCUSSION

In this section we want to discuss how the experimental results of Au reported here fit in with analogous data on other elements (Rh, In), and whether these results can be understood on the basis of statistical theory.

There is one salient difference between $\sigma(h\nu)$ for $Au(\gamma,\gamma')Au^m$ (as reported here) and the cross sections of the two lighter elements: gold exhibits, with great likelihood, *two* peaks, whereas single peaks have been reported for Rh [4] and In.[5] The authors of the measurements on these latter elements have furthermore shown that their data were substantially in agreement with statistical theory. It would thus appear (if one wants to believe in that theory in which all parameters are smooth functions of A) that either (a) our present data are suspect, or (b) the data on In and Rh have been improperly taken and/or interpreted. We shall adopt point of view (b); however, even then it will be necessary to modify the statistical approach as presented, e.g., in I. To make this modification clear, we present a brief summary of the theory used in I: one predicts the approximate cross section, $\sigma_{\rm obs}(\gamma,\gamma')$ for inelastic scattering processes leading to the isomer:

$$(\mathrm{I},1)\quad \sigma(\gamma,\gamma')_{\rm obs}=\alpha^{-1}\sigma_{\rm abs}(E_a)\left(\frac{\Gamma_\gamma}{\Gamma_\gamma+\Gamma_n}\right)_{E_a}\times\left\{\left(\frac{\Gamma_\gamma-\Gamma_<}{\Gamma_\gamma}\right)_{E_a}+\left(\frac{\Gamma_<}{\Gamma_\gamma}\right)_{E_a}\left(\frac{\Gamma_\gamma}{\Gamma_\gamma+\Gamma_n}\right)_{E'}\right\},$$

where α = branching ratio (ground state/isomer), $\sigma_{\rm abs}$ = total absorption cross section, E_a = initial excitation energy (Mev), $\Gamma_\gamma=\Gamma_<+\Gamma_>$ = total γ width, $\Gamma_<$ = γ width for emission of $\hbar w\leqslant E_a-\epsilon$, ϵ = neutron binding energy, Γ_n = neutron width, and E' = some mean energy

[9] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953).
[10] Martin, Diven, and Taschek, Phys. Rev. **93**, 199 (1954).
[11] E. Hayward and E. G. Fuller, Phys. Rev. **95**, 1106 (1954).
[12] H. Bethe and J. Ashkin, *Experimental Nuclear Physics*, edited by E. Segrè (John Wiley and Sons, Inc., New York, 1953), Vol. 1, p. 347.
[13] Burkhardt, Winhold, and Dupree, Phys. Rev. **100**, 199 (1955).

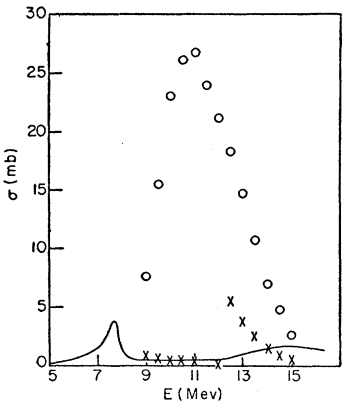

FIG. 5. Experimental cross section for $Au^{197}(\gamma,\gamma')Au^{197m}$ in comparison with predictions of statistical theory: (———) experiment; (O O O), assuming emission width $\Gamma_\gamma=\Gamma_{E1}(E_a)$ for all E_a; (× × ×) theory, assuming $\Gamma_\gamma=\Gamma_{M1}(E_a)$ for $E_a\leqslant 12$ Mev, $\Gamma_\gamma=\Gamma_{E1}(E_a)$ for $E_a>12$ Mev.

such that $\epsilon\leqslant E'\leqslant E_a$. σ_{abs} can be obtained from experiments as it is well approximated by $\sigma(\gamma,xn)$ for medium and large A. Statistical theory gives both the neutron and γ widths; both depend on the assumed level density and nuclear radius, and γ widths depend in addition on the multipolarity as well as on the independent-particle or collective nature of the transition. In I the level density parameters and nuclear radius given by Blatt and Weisskopf[14] (except $D_0=1$ Mev) and Γ_γ *was calculated assuming E1 transitions of uninhibited independent particle strength* (reference 14, p. 649) *at all energies.*

Figure 5 shows (O) $\sigma(\gamma,\gamma')_{\text{obs}}$ calculated for Au^{197} under the assumptions of I; σ_{abs} was taken from $\sigma(\gamma,xn)$,[9] and α was assumed to be 5. The violent discrepancy with our experimental data (plotted in the same figure) is manifest. It is clear that Γ_γ/Γ_n has to be reduced drastically near and above $E_a\approx\epsilon$ to force a sudden fall-off near threshold. We can do this within the framework of I by relaxing the assumption about Γ_γ at least in this energy region. As there have been some conjectures[14] that near threshold γ absorption takes place by $E2+M1$ transitions rather than $E1$, we have computed $\sigma(\gamma,\gamma')_{\text{obs}}$ *assuming that* $\Gamma_\gamma=\Gamma_{M1}$ *for* $E_a\leqslant 12$ *Mev,* $\Gamma_\gamma=\Gamma_{E1}$ *for* $E_a>12$ *Mev.* The result is indicated by (×) in Fig. 5. The general features of the experiment are now well reproduced, in particular as the behavior for $E_a<\epsilon$ is not dependent on these assumptions. The second peak could easily be displaced from 12.5 to 15 Mev by making the change from $M1$ and $E1$ more gradual. Assuming $E2$ instead of $M1$ leads to an even sharper drop at $E_a\approx\epsilon$.

[14] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), pp. 389, 649.

One has now to see how the data on In and Rh can be interpreted if one accepts this modification of the theory. The cross sections obtained for these elements are, in our opinion, much less reliable than the present data on Au because the yield curves were taken at points separated by larger energy intervals. We have re-evaluated the Rh as well as the In yield curves[3,5] and find that both are compatible with cross sections of an energy dependence very similar to that of $Au(\gamma,\gamma')$. It is to be pointed out that Burkhardt *et al.*[13] find in In a peak near threshold, in contrast with reference 5; their work is limited to energies too low to excite a possible second peak.‡ We have explored the hypothesis that $\Gamma_\gamma(E_a)$ is due mainly to $M1$ or $E2$ transitions below and near threshold. This hypothesis, however, is incompatible with elementary selection rules. To each $Au^{197m}(h_{11/2}^-)$ from the ground state of $Au^{197}(d_{3/2}^+)$, one (or an odd number) transition with change of parity is required; hence any combination involving *only* $E2$ and $M1$ transitions is excluded.

If the absorption is at all energies prevalently E_1, then there will always be at least two $E1$ steps in the de-excitation.[15] Conversely, if in any region the absorption takes place by $E2$ and/or $M1$, de-excitation will involve one (or an odd number) of $E1$ steps. In any step, the multipolarity supplying the greatest partial width Γ_γ will dominate and compete with Γ_n. Even under anomalous circumstances $\Gamma_{E1}(E_a)$ will be at least as large as $\Gamma_{E2,M1}(E_a)$, and thus the first step in the de-excitation will most likely be $E1$ independent of the absorption mechanism. Hence our experiments lead to no safe conclusions as to the nature of the absorption act, but imply only that the $\Gamma_{E1}(E_a)$'s are smaller than the Weisskopf estimates for $E_a\leqslant 12$ Mev, namely that they are of magnitudes comparable to his esimates for $\Gamma_{E2}(E_a)$ or $\Gamma_{M1}(E_a)$.

The minimum number of de-excitation steps depends on the multipolarity of the absorption. A change in the latter might also imply that $\alpha=\alpha(E_a)$, i.e., that the de-excitation branching ratio is not essentially independent of energy.

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‡ *Note added in proof.*—The reincrease in the cross section for $In^{115}(\gamma,\gamma')In^{115m}$, after a first peak at 8.6 Mev, has been found recently by Bogdankevich, Lazareva, and Nicolaev (Abstract at the Amsterdam Conference, July 1956).

[15] Disregarding all non-$E1$ transitions with parity change because of their slowness.