Energy Levels of Au^{195}†

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The energy levels of Au^{195} were studied by observation of conversion electrons following the $(p, 2n)$ reaction on Pt^{196}, and by measurement of the energy spectrum and angular distribution of tritons from the $Au^{197}(p,t)$ reaction. Many new energy levels are reported, and several new I-π assignments are made by combining information from the two experiments.

The excited levels of Au^{195} have been previously studied[1] by the decay of the ground state and metastable excited state of Hg^{195}. The present experiment utilizes charged-particle reactions leading to final states in Au^{195}. They are the observation of conversion electrons following the $(p, 2n)$ reaction on Pt^{196}, and the detection of tritons from the Au^{197}-$(p, t)Au^{195}$ reaction. Several new levels were identified and assigned spins and parities.

The experiments were performed using the University of Pittsburgh three-stage Tandem Van de Graaff accelerator. The $Au^{197}(p, t)Au^{195}$ reaction was induced with 17-MeV protons, and the tritons were detected by photographic plates in the focal plane of an Enge split-pole spectrograph. A description of the magnet and scattering system has been given elsewhere.[2] Because of the large negative Q value (−6.2 MeV), only states up to 1.6 MeV in excitation were observed. Spectra were obtained at eight angles from 8 to 65°, and a typical one is shown in Fig. 1. Since the ground state is excited with a cross section typically two orders of magnitude larger than those of the excited states, the peak from it was overexposed on the plates, so it was studied in a separate experiment using a position sensitive detector in the focal plane of the magnet. The resolution in the early runs was approximately 10 keV, but when it became apparent that good resolution was not necessary (i.e., the states were well separated) thicker targets and a larger solid angle were used in order to cut down the long running times. The targets used were made from gold leaf and ranged in thickness from 300 μg in the early runs to 1 mg in the later runs. The gold leaf contains significant impurities of silver and copper, but the Q value of reactions from these impurities is such that in the region of interest, kinematics excluded all charged particles except the tritons from the $Au^{197}(p, t)$ reaction. The only problem encountered was background due to beam scattered from the defining slit in front of the target. Since resolution was not a problem, this background was removed by going to a slightly larger slit and tuning the beam completely off the slit. The uncertainties in excitation energies are about 10 keV in the 1-MeV excitation region, and 5 keV at lower excitations.

The conversion electrons from the $Pt^{196}(p, 2n)$-Au^{195} reaction were observed in a six-gap "orange" type spectrometer originally designed by Kofeod-Hanson.[3] A description of the magnet and its associated electronics is given elsewhere.[4] Data were taken at bombarding energies of 8, 10, 12, and 16 MeV. This range of energies was necessary in order to distinguish between the peaks from the (p,n) and $(p, 2n)$ reactions. The $(p, 2n)$ threshold is at 8.5 MeV. A typical spectrum is shown in Fig. 2. The resolution was about 1% in momentum. The target was a thick (2–4-mg/cm^2) self-supporting foil of 70% enriched Pt^{196} with the principal impurity being Pt^{195} (~20%).

The difficulty in working with conversion electrons is that only transition energies are determined and not energy levels. This is partially compensated for by the fact that the multipolarity of the transition can usually be determined from the intensity ratios of the K and L conversion lines. The (p, t) reaction determines energy levels but not spins and parities. [This is not the case at higher bombarding energies where there is structure in the angular distributions. This lack of structure in the angular distributions precluded any use of distorted-wave Born-approximation (DWBA) calculations.] The combination of the two experiments can then give the desired results since the determination of energy levels also determines the assignment of the observed transitions.

The triton angular distributions for all transitions are plotted in Figs. 3 and 4. With the exception of transitions to the ground state and the 1.35-MeV state (cf. Fig. 4), the angular distributions are generally not differentiable. Since the ground state of Au^{195} is $\frac{3}{2}^+$, the transition from Au^{197} (whose ground state is also $\frac{3}{2}^+$) must be an $L=0$ transition. The similarity of this angular dis-

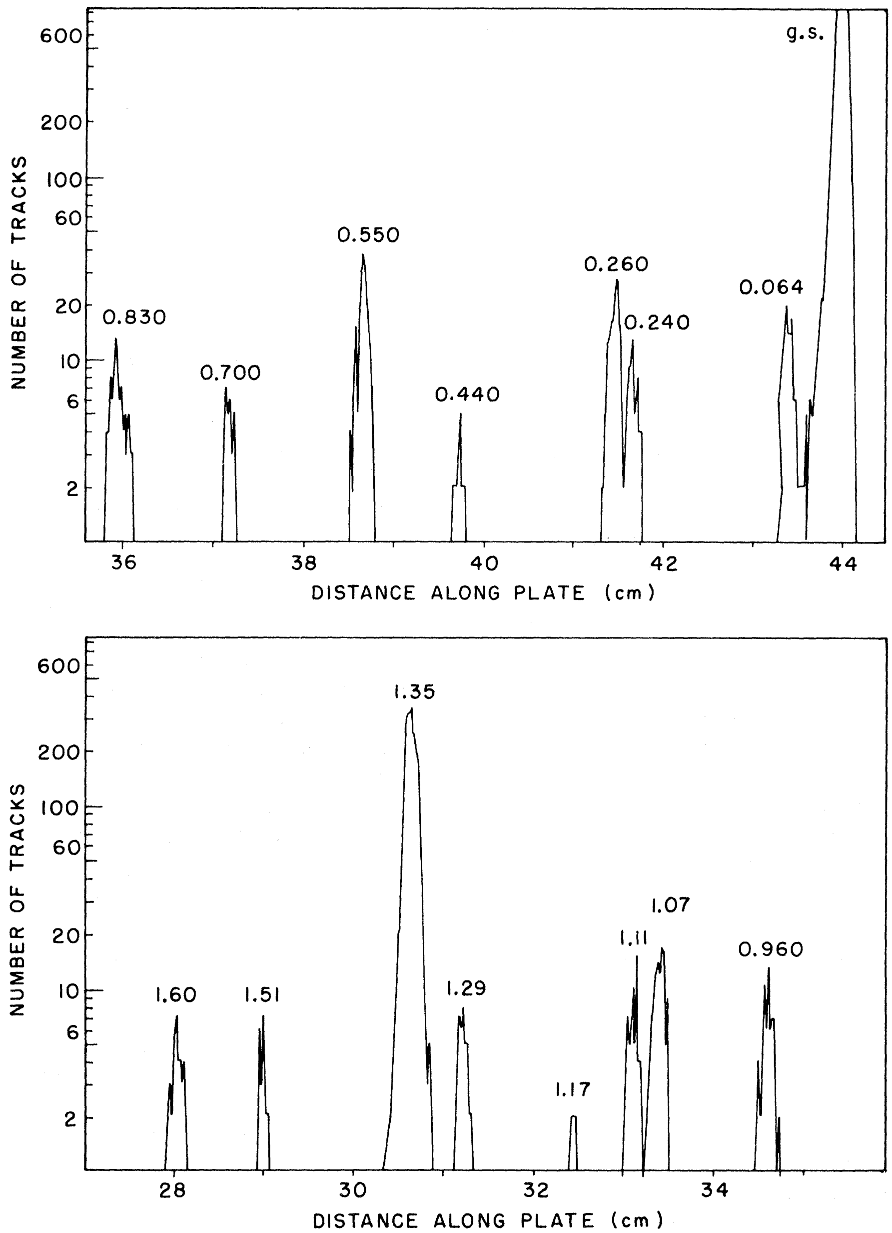

FIG. 1. Energy spectrum of tritons from the reaction $Au^{197}(p,t)Au^{195}$. Observation angles are 75° in upper portion and 15° in lower portion. Numbers are excitation energies of corresponding states in MeV.

tribution to that for transitions to the 1.35-MeV state indicates that the latter is also a $\frac{3}{2}^+$ state. The energies of all transitions observed plus relative intensities at the maxima are listed in Table I.

The energies and intensities of the electron spectrum from the $Pt^{196}(p, 2n)Au^{195}$ reaction with $E_p = 16$ MeV are listed in Table II. Several transitions are identified with the aid of the (p, t) results and previously known levels.

The 440-keV level had not been reported in earlier studies, but it is observed in the (p, t) reaction, and a 440-keV transition is observed in the electron spectrum. The K/L ratio for this transition is 6.3 ± 0.8 which implies an $M1$ transition (theoretical value $=6.0$). Thus, only three possible spins and parities are possible for the 440-keV level, namely $\frac{1}{2}^+$, $\frac{3}{2}^+$, and $\frac{5}{2}^+$. A $\frac{3}{2}^+$ assignment is doubtful because in this case the angular distribution from the (p, t) results should show the characteristic $L=0$ shape whereas, as seen in Fig. 3, the angular distribution for transitions to the 440-

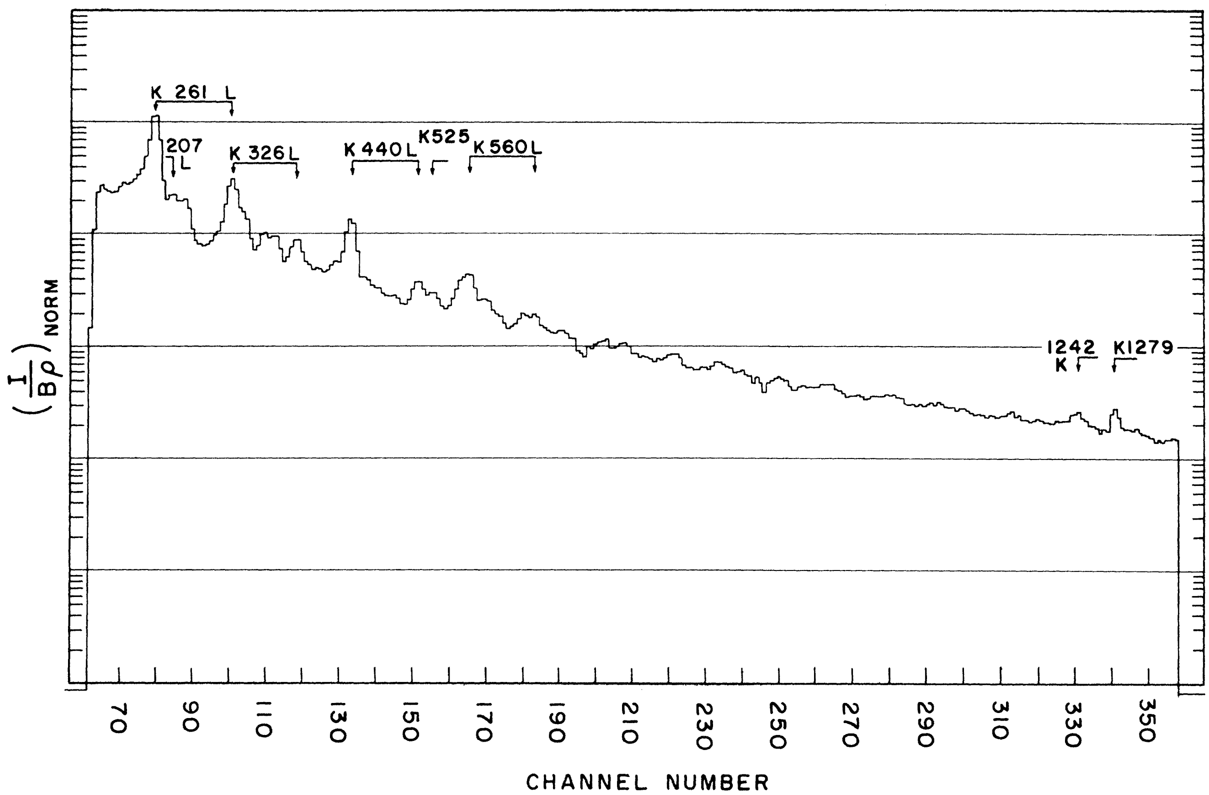

FIG. 2. Energy spectrum of electrons emitted following bombardment of Pt^{196} by 16-MeV protons. The peaks identified by arrows appeared consistently in all runs are listed in Table II. Data are normalized to the same number of incident protons for each channel.

keV state is relatively flat. The $\frac{1}{2}^+$ assignment is a possibility, but such a level would probably decay to the $\frac{1}{2}^+$ 0.062-MeV level as well as the $\frac{3}{2}^+$ ground state, and no 380-keV transition was observed. Therefore, the most probable assignment for this level is $\frac{5}{2}^+$.

The 555-keV level has not been previously reported in radioactive decay but is observed in both experiments here. In the (p, t) results, the excitation energy of this state was 550 ± 10 keV, while in the electron spectrum the result was 560 ± 7 keV. In this case the K/L ratio is 3.0 ± 0.8 which implies an $E2$ transition (theoretical value 3.8). The possible assignments for this level are therefore $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$. The first two ($\frac{1}{2}^+$, $\frac{3}{2}^+$) are doubtful for the same reasons as in the case of the 440-keV level. A $\frac{5}{2}^+$ assignment is doubtful because there would be strong competition for such a level to decay to the ground state via an $M1$ transition as well as by an $E2$ transition. Therefore, the most probable assignment for the 555-keV level is $\frac{7}{2}^+$.

TABLE I. States excited in $Au^{197}(p,t)Au^{195}$ reactions at $E_p = 17$ MeV.

Excitation energy (MeV)	Maximum intensity (arbitrary)	θ of maximum intensity
0.0	20 600	15
0.064	202	22
0.240	138	15
0.260	374	22
0.440	34	36
0.550	522	8
0.700	79	22
0.830	259	22
0.960	157	22
1.07	218	15
1.11	121	15
1.17	23	30
1.29	1790	8
1.35	4804	15
1.51	43	15
1.60	75	15

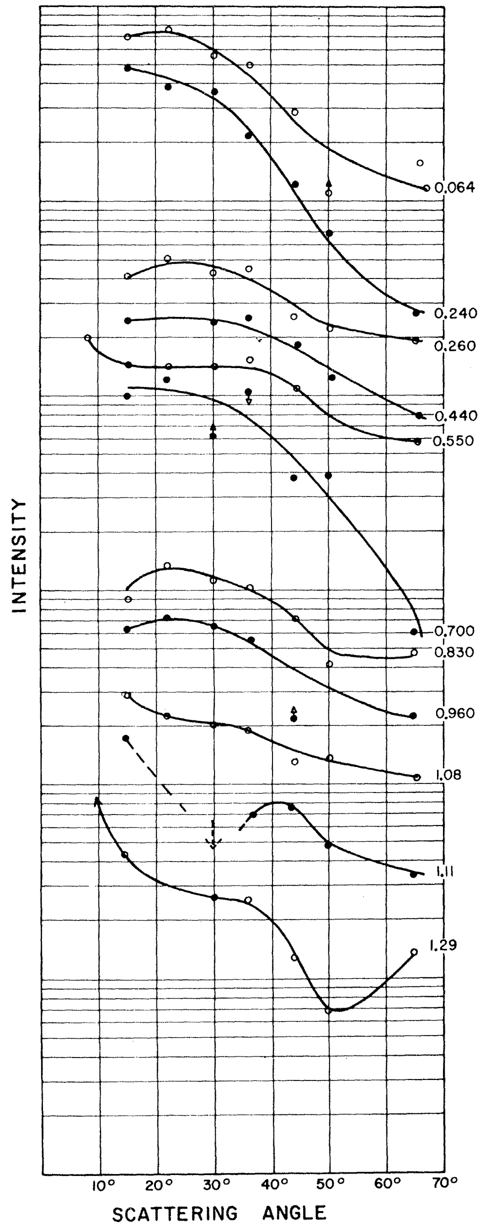

FIG. 3. Angular distributions of tritons from transitions leading to final states of excitation energy indicated (in MeV) by the attached numbers.

In the radioactivity work, there was a tentative identification of a level at 525 keV. This level is not seen in the (p, t) results (upper limit is $\frac{1}{10}$ that of the weakest state observed), but in the internal conversion results a weak 525-keV transition is seen (the L line is too weak to be seen) along with the L line of a 207-keV transition (the energy difference between a 525-keV level and the 320-keV $\frac{11}{2}^-$ level). The absence of a peak in the (p, t) spectrum makes the assignment uncertain.

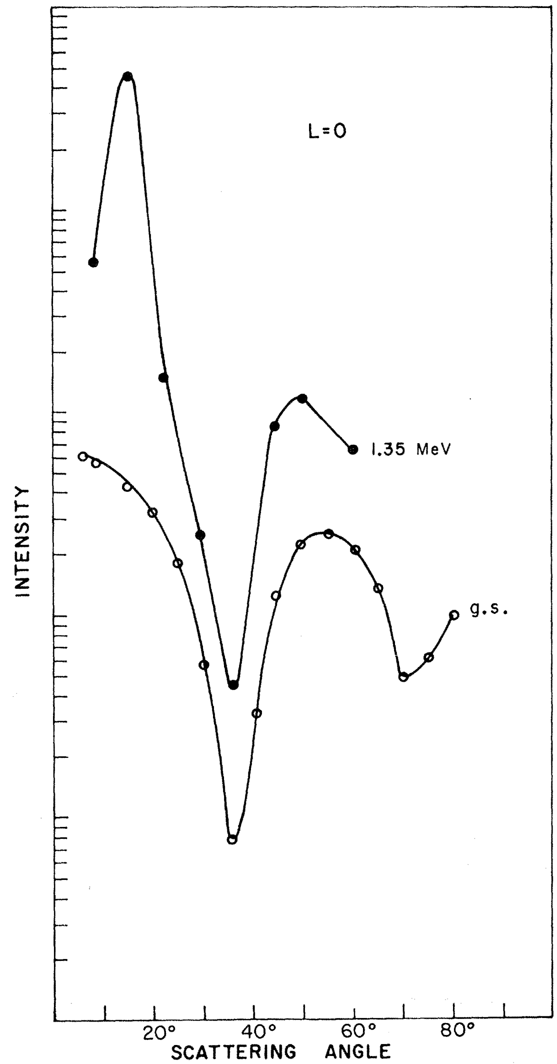

FIG. 4. Angular distributions of tritons from transitions leading to final states of excitation energy indicated (in MeV) by the attached numbers. These angular distributions are chacteristic of $L=0$ transfer.

In the high-energy portion of the electron spectrum two peaks appear at 1242 and 1280 keV. The 1242-keV transition has been observed in radioactive decay. The 1280-keV transition could possibly be the direct decay of the known 1280-keV level to the ground state.

Figure 5 is a diagram of the excited states of Au^{195} showing the newly reported levels discussed in this paper. In addition to the transitions mentioned above, two previously reported transitions were observed in the internal conversion work. They are the 260-keV level decaying to the ground state and the 320-keV $\frac{11}{2}^-$ level decaying via an isomeric transition (31 sec) to the ground state.

TABLE II. Conversion electron lines from $Pt^{196}(p,2n)Au^{195}$ reactions at $E_p=16$ MeV.

Electron energy (keV)	Electron intensity (arbitrary)	Transition energy (keV)	K/L ratio	Comments
180 ± 4	320	261K + 200L		$\frac{5}{2}^+ \to \frac{3}{2}^+$ (g.s.)
194 ± 4	15	207L		0.525 → 0.319 ?
204 ± 4	16			
245 ± 4	90	326K + 260L		$\frac{11}{2}^- \to \frac{3}{2}^+$ (g.s.)
254 ± 4	18			
277 ± 5	12			
286 ± 5	8.4			
307 ± 5	6.3	326L		
359 ± 6	30	440K	6.3 ± 0.8	$\frac{5}{2}^+ \to \frac{3}{2}^+$ (g.s.)
429 ± 7	4.8	440L		
444 ± 7	2.6	525K		0.525 → g.s. ?
479 ± 8	12	560K	3.0 ± 0.8	$\frac{7}{2}^+ \to \frac{3}{2}^+$ (g.s.)
550 ± 8	4.0	560L		
1161 ± 15	0.18	1242K		1.558 → 0.319 ?
1200 ± 16	0.24	1279K		1.279 → g.s.

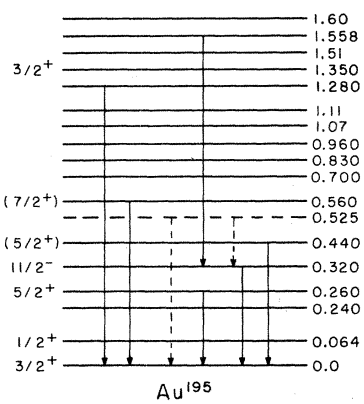

FIG. 5. Transitions and energy levels in Au^{195} observed in the present work.

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