Internal Conversion Spectrum of Au^{198}†

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An absolute energy determination for the internal conversion electrons from Au^{198} has been made with our electrostatic analyzer. The gamma-ray energy has been determined from these results to be 411.76±0.19 kev. The intensity ratios (L_I:L_{II}:L_{III}) in the L subshell are found to be (1.9±0.3):(2.2±0.3):1.0, in agreement with theory for an $E2$ transition. A determination of the internal conversion coefficients gave $\alpha_K=0.025\pm0.005$ and $\alpha_L=0.012\pm0.002$.

INTRODUCTION

THE 2.69-day activity of Au^{198} is known[1] to decay primarily by a beta decay of end-point energy 963 kev to an excited state in Hg^{198} which then decays either by gamma emission or internal conversion to the ground state. The gamma ray and the conversion lines are frequently used as calibration standards in nuclear spectroscopy. The following are the most recent and the most accurate energy determinations. Muller, Hoyt, Klein, and DuMond[2] have measured the gamma-ray energy with their curved crystal spectrometer. Hedgran and Lind[3] have determined the transition energy from its K internal conversion line and also from external conversion in uranium using a beta spectrometer calibrated against Co^{60}, the Th L line, and the $E_K-E_{L_I}$ energy difference in uranium. In the present investigation an absolute energy measurement of the internal conversion electrons has been made by using our electrostatic analyzer.

This electrostatic analyzer is capable of high resolution, and thus it was possible to resolve the individual L subshell internal conversion lines. The intensity ratios in this subshell serve as a check on the recent theoretical results of Rose[4] at this particular value of atomic number and energy.

EXPERIMENTAL

The two-foot radius, 90°, cylindrical electrostatic analyzer used in this investigation has been described by Noyes, Van Hoomissen, Miller, and Waldman,[5] who used this analyzer to measure the threshold energies for the photodisintegration of deuterium and beryllium. The accuracy has been increased to 0.05% by improving the voltage measurement and stabilization, by a new method of measuring the separation between the cylindrical electrodes, and by using suitable shielding to reduce the correction due to the earth's magnetic field. The resolution was set at 0.09%.

The solid angle subtended by the analyzer is very small and consequently the transmission was only 0.001%, necessitating a high specific activity source. This source was prepared by evaporating about 1 mg/cm² of gold onto an aluminum foil (1 mil thick), and irradiating this in the Argonne CP-5 reactor. The initial specific activity of this source was 100 mC/mg. A time of twenty-four hours was allowed for the aluminum to decay before data were taken. The electron detector at the exit slit of the analyzer was a thin plastic scintillator and photomultiplier. The thickness of this phosphor was 0.5 mm, corresponding to a probable energy loss of about 50 kev for electrons passing through it. The efficiency of the phosphor was assumed to be constant over the energy range covered in this investigation.

RESULTS AND DISCUSSION

Energy Determination

Figure 1 shows the portion of the electron energy spectrum in the vicinity of the conversion lines. The general background due to the beta decay is nearly linear over the energy range covered by Fig. 1. Thus, the beta background under any of the conversion peaks was approximated by a straight line drawn

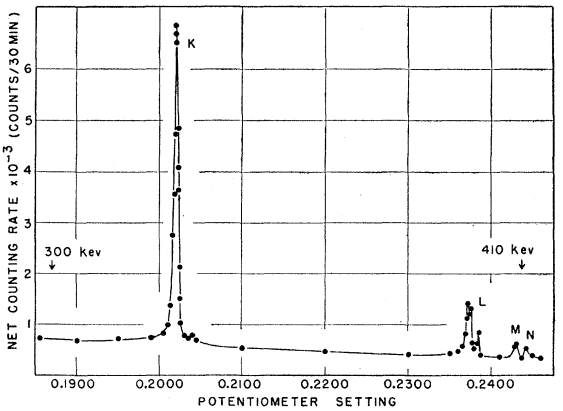

FIG. 1. Internal conversion spectrum of Au^{198}. The potentiometer setting is a measure of the energy of the electrons which will pass through the electrostatic analyzer.

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[2] Muller, Hoyt, Klein, and DuMond, Phys. Rev. 88, 775 (1952).

[3] A. Hedgran and D. Lind, Arkiv. Fysik 5, 177 (1952), and 5, 29 (1952).

[4] M. E. Rose in *Beta and Gamma Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 905.

[5] Noyes, Van Hoomissen, Miller, and Waldman, Phys. Rev. 95, 396 (1954).

from the point at 300 kev to one at 410 kev. The width of the K line at half-maximum is about 1 kev and is due to straggling in the source. Consequently, the K electron energy was determined by extrapolating its high-energy edge to the beta background.

Figure 2 shows the region of the L conversion lines. The individual L_I and L_{II} lines were unfolded from the composite profile by a comparison with the shape of the L_{III} line. Then individual L electron energies were determined by extrapolation of their high-energy edges.

Table I shows the results of the energy determination. The error shown is the maximum uncertainty in the absolute energy of the electrons. The binding energies in mercury were taken from the data of Hill, Church, and Mihelich.[6]

Table II compares the results of this investigation with the results of Muller *et al.*[2] and Hedgran and Lind.[3] The results of other workers, whose uncertainty was larger than 1 kev, are not included in this tabulation.

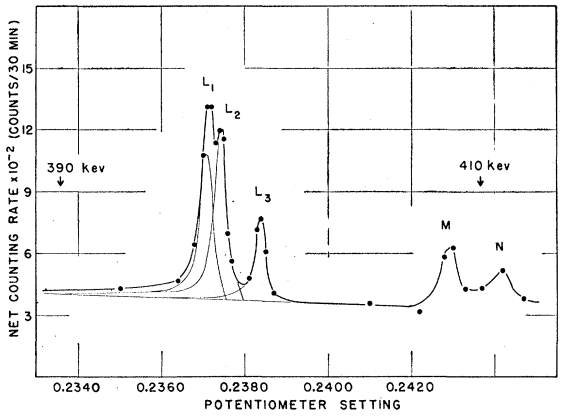

FIG. 2. L, M, and N internal conversion lines in Au^{198}.

Subshell Ratios

The intensity ratios (L_I:L_{II}:L_{III}) in the L subshell are as follows:

Experimental	(1.9±0.3)	: (2.2±0.3)	:1.0.
Theoretical ($E2$)	2.2	: 2.4	:1.0.

The theoretical ratios are interpolated from the data of Rose[4,7] for a pure electric quadrupole transition. Other investigators[1] have shown that the transition is probably $E2$.

Conversion Coefficients

In order to determine the internal conversion coefficients for the decay of the 411.8-kev state of Hg^{198}, we have made use of the fact[1] that 98% of the decay of Au^{198} feeds this state. Thus the population of the 411.8-kev state can be found from the total number of betas emitted by the gold. However, the usual method of determining the total number of betas by measuring the entire beta spectrum was not convenient since the position of optimum focus of an electrostatic analyzer varies with energy. Therefore our problem was to determine the total number of betas from the number observed in a small segment of the beta spectrum.

From the theory of beta decay, it can be shown that, for a decay having an allowed shape, the fraction of the total number of betas occuring in a small energy interval, ΔW, at electron energy W, is

$$\frac{\Delta\lambda}{\lambda}=\frac{F(Z,W)(W_0-W)^2(W^2-m^2c^4)^{\frac{1}{2}}W\Delta W}{m^5c^{10}f},$$

where

$$f=\frac{1}{m^5c^{10}}\int_{mc^2}^{W_0}F(Z,W)(W_0-W)^2(W^2-m^2c^4)^{\frac{1}{2}}W\,dW.$$

$F(Z,W)$ is the Coulomb factor and is tabulated in Appendix II of Siegbahn.[4] W_0 is the end point energy in units of mc^2 and W is the total electron energy in units of mc^2. We have evaluated the denominator of this fraction according to the work of Feenberg and Trigg.[8] The numerator was evaluated at the energy of the K line for an energy interval, ΔW, equal to the resolution of the analyzer. Then, using this fraction and the number of betas observed in this energy interval, we obtained the population of the 411.8-kev state and subsequently the K conversion coefficient. A similar procedure was used to determine α_L.

This method of determining the conversion coefficients eliminates any effect of the equipment since both the conversion electrons and the betas of the same

TABLE I. Experimental energy values of K and L lines in Au^{198}.

Line	Electron energy[a] (kev)	Binding energy (kev)	Transition energy (kev)
K	328.70±0.16	83.10±0.05	411.80±0.17
L_I	396.90±0.20	14.84±0.05	411.74±0.21
L_{II}	397.45±0.20	14.21±0.05	411.66±0.21
L_{III}	399.38±0.20	12.28±0.05	411.66±0.21

[a] The error shown is the maximum uncertainty in the absolute energy of the electrons.

TABLE II. Au^{198} gamma-ray energies.

References	Gamma-ray energy (kev)
Muller, Hoyt, Klein, and DuMond	411.77±0.036
Hedgran and Lind[a]	411.1 ±0.4
Hedgran and Lind[b]	411.5 ±0.4
Hedgran and Lind[c]	411.75±0.10
Present investigation[d]	411.76±0.19

[a] Measured relative to the Co^{60} γ rays.
[b] Measured relative to the E_K-E_{LI} energy difference in uranium.
[c] Measured relative to the Th L line.
[d] Weighted mean of the K determination and the average of the L determinations in Table I.

[6] Hill, Church, and Mihelich, Rev. Sci. Instr. **23**, 523 (1952).
[7] M. E. Rose (private communication).
[8] E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).

energy are emitted within the same solid angle and are counted with equal efficiency. However, the method is applicable only to a source which has a simple decay scheme in which the beta spectrum has an allowed shape.

The values which we obtained are $\alpha_K=0.025\pm0.005$ and $\alpha_L=0.012\pm0.002$ in agreement with the results of other investigators.[1] An interpolation of the results of Rose, Goertzel, and Swift,[9] which include screening, gives $\alpha_K=0.031$ and $\alpha_L=0.012$.

CONCLUSION

Our results for the absolute electron energies, when combined with the best available absorption edge energies, are in agreement with the absolute gamma ray measurement of Muller, Hoyt, Klein, and DuMond. If one assumes their value for the gamma-ray energy, then our results serve as a check on the absorption edge energies and are in agreement to within our quoted uncertainty.

The agreement between the experimental and theoretical L subshell intensity ratios shows that the theoretical results may be used with confidence at least in the vicinity of $Z=80$, $E=400$ kev, and for an $E2$ transition.

[9] Rose, Goertzel, and Swift (privately distributed tables).

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Calculation of Electron-Deuteron Scattering Cross Sections*†

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Elastic and inelastic cross sections for electron-deuteron scattering with large momentum transfer have been investigated. The calculation has been performed in the first Born approximation. The neutron-proton interaction has been described by a phenomenological potential, and the nucleons have been represented by point charges and point magnetic moments. Finite size of nucleons causes major correction to these results.

I. INTRODUCTION

THE scattering of electrons with large momentum transfer has yielded some new and quite definite information about the charge distribution in a number of heavy nuclei. Experimental accuracy is improving to such an extent that this method holds promise of yielding new information even when applied to a relatively simple and well-understood nucleus, such as the deuteron. Some measurements[1] have already been made, in which the deuteron has been bombarded by high-energy electrons and the energies of the electrons scattered at large angles have been measured. A narrow elastic peak has been obtained, and a wide inelastic peak, corresponding to the breakup of the deuteron, has also been observed.

A few calculations[2] intended mainly for small momentum transfers have already been made. These calculations of elastic cross sections still give quite accurate results even at large momentum transfers. On the other hand, in the calculations of inelastic cross sections only the lowest electric and magnetic multipole moments have been considered. These results cannot be applied to the scattering with large momentum transfer when the contribution of higher multipole moments is quite important. Thus, it is necessary to perform a calculation that accounts for all multipoles.

Since the interaction between electron and nucleus is of electromagnetic nature, the matrix elements involved are similar to those used in calculating the photodisintegration of the deuteron. Calculations[3] and experimental data are plentiful in this case. The results cannot, however, be easily applied to our case, since in the photoprocess we have only real (transverse) photons, while in the electrodisintegration the main contribution comes from the longitudinal part of the

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