The Nuclear Excitation of Ag^{107} and Ag^{109} by X-Rays*

ELIGIUS J. WOLICKI,† BERNARD WALDMAN, AND WALTER C. MILLER
Department of Physics, University of Notre Dame, Notre Dame, Indiana
(Received January 15, 1951)

X-rays, produced by monoergic electrons, were used to excite the separated isotopes of silver to their metastable states. The half-life of Ag^{107*} was found to be 44.0±1.0 seconds. The half-life of Ag^{109*} was found to be 40.0±1.0 seconds. These measurements are in agreement with those of Bradt, *et al.*, and the isotopic assignment of Helmholz. The electron energy was varied between 0.8 Mev and 2.3 Mev in order to obtain the excitation curves. The thresholds for x-ray excitation of both Ag^{107} and Ag^{109} were found to be below 0.8 Mev. An activation level in Ag^{107} was found at 1.285±0.018 Mev. An activation level in Ag^{109} was found at 1.210±0.018 Mev. The over-all cross section (i.e., per incident electron on thick gold target) is of the order of 10^{-34} cm² for both isotopes at 1.4 Mev.

I. INTRODUCTION

THE x-ray excitation of the isomeric state of silver was first observed by Collins and Feldmeier.[1] Further work[2] showed that, similar to indium,[3] one could obtain, from an x-ray excitation curve, two activation levels, at 0.85 Mev and 1.25 Mev. Wiedenbeck[4] repeated these experiments and was able to analyze the resulting x-ray excitation curve into evidence for some six activation levels, at 1.18, 1.59, 1.95, 2.32, 2.76, and 3.13 Mev. All of these experiments used ordinary silver consisting of essentially equal parts of the two isotopes 107 and 109.

The original investigation of Alvarez, Helmholz, and Nelson[5] established the metastable state in silver by a study of the decay of cadmium but did not identify the isotope. Helmholz[6] showed that in order to account for the presence of two internally converted gamma-rays, it was necessary to postulate that both isotopes of silver had metastable states of approximately 40-sec half-life. Bradt, *et al.*,[7] measured the half-lives and associated disintegration schemes of cadmium and silver, not knowing the isotopic assignment until Helmholz[8] identified the parent cadmium isotopes. The 94-kev gamma-ray of half-life 44.3 sec was assigned to Ag^{107*}, and the 89-kev gamma-ray of half-life 39.2 sec was assigned to Ag^{109*}.

With the availability of the separated isotopes of silver, it became desirable (a) to determine *directly* the half-lives and isotopic assignments, and (b) to obtain the x-ray excitation curve for each isotope.

The analysis and interpretation of x-ray excitation curves has been discussed by Miller and Waldman.[3]

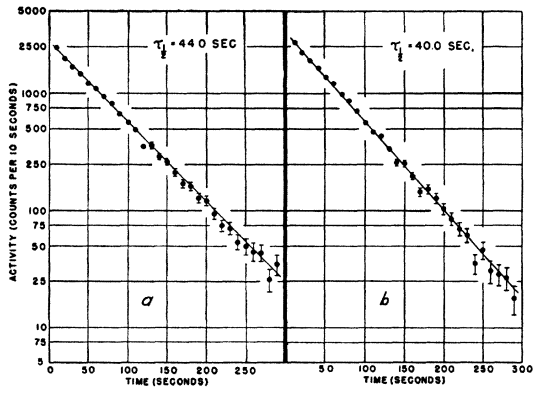

FIG. 1. (a) Decay of Ag^{107*}. (b) Decay of Ag^{109*}.

II. EXPERIMENTAL PROCEDURE

(A) Irradiation

The separated isotopes of silver were obtained as chlorides, and metallic foils were prepared by electroplating on platinum disks $\frac{7}{8}''$ in diameter. The isotopic proportions and the foil thicknesses were as follows. The Ag^{107} contained 3.2 percent of Ag^{109} and was 10.3 mg/cm² thick; the Ag^{109} contained 0.1 percent of Ag^{107} and was 10.8 mg/cm² thick. These thicknesses were greater than the range of the conversion electrons to be detected.

The x-rays were produced with the Notre Dame electrostatic generator by stopping a well-collimated beam of monoergic electrons in a thick ($\frac{1}{16}''$) gold target. As in previous experiments,[3] the current was monitored by a Brown recording potentiometer, and the voltage was measured and stabilized by a null-type generating voltmeter and associated control circuits. The voltage calibration was based on the photo-disintegration thresholds of beryllium and deuterium as measured by Mobley and Laubenstein.[9]

(B) Counting

The activities encountered in this experiment were low owing to the following facts:

* This work was supported by the joint program of the ONR and AEC.
† AEC Predoctoral Fellow; now at the University of Iowa, Iowa City, Iowa.

[1] G. B. Collins and J. R. Feldmeier, Phys. Rev. **59**, 937 (1941).
[2] J. R. Feldmeier, Ph.D. thesis, Univ. of Notre Dame (1942).
[3] W. C. Miller and B. Waldman, Phys. Rev. **75**, 425 (1949).
[4] M. L. Wiedenbeck, Phys. Rev. **67**, 92 (1945).
[5] Alvarez, Helmholz, and Nelson, Phys. Rev. **57**, 660 (1940).
[6] A. C. Helmholz, Phys. Rev. **60**, 160 (1941).
[7] Bradt, Gugelot, Huber, Medicus, Preiswerk, Scherrer, and Steffen, Helv. Phys. Acta **20**, 153 (1947).
[8] A. C. Helmholz, Phys. Rev. **70**, 982 (1946).
[9] R. C. Mobley and R. A. Laubenstein, Phys. Rev. **80**, 309 (1950).

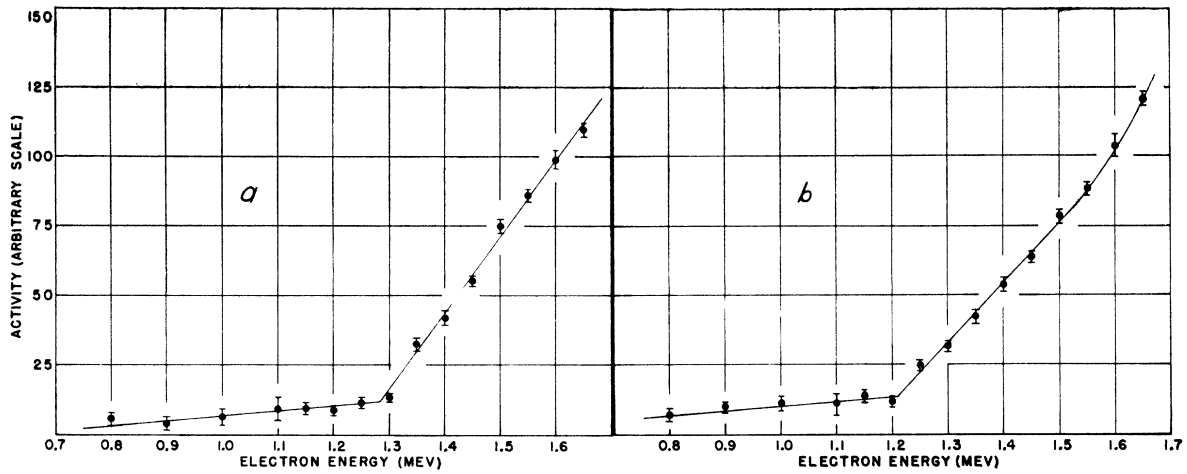

FIG. 2. (a) Thick target x-ray excitation curve of Ag^{107}. (b) Thick target x-ray excitation curve of Ag^{109}.

(1). *Small cross section.* This necessitated large electron beam currents (250 μamp average).

(2). *Short half-life.* This required a minimum delay between the end of the irradiation and the beginning of the counting. This delay was reduced to considerably less than one half-life.

(3). *Low energy conversion electrons.* Since the absorption of thin (1.5 mg/cm^2) windows in Tracerlab and similar counters was found to be prohibitive, it was necessary to place the irradiated foil within the counter itself. Silver-cathode, argon-ether filled counters, after irradiation by the intense x-ray beam, had a high counting rate due to increased photosensitivity. The counting rate could be reduced by light shielding. Nevertheless, light-tight counters thus irradiated showed a spurious activity which persisted after the silver activity had decayed. Evacuated silver-cathode counters were irradiated and filled, immediately after irradiation, with a non-irradiated gas mixture. These, too, exhibited a small activity having a half-life greater than 10 times that of the metastable silver. A 0.1 mg/cm^2 coating of zapon lacquer on the silver reduced, but did not obliterate, this spurious activity. Finally, a Nuclear Instrument Corporation "*Q*-gas" flow counter was used. This was modified so that the sample holder was flushed with *Q*-gas before the sample was introduced into the counting volume. This reduced the waiting period for reliable counting from about 200 to about 10 sec. The total delay time between the end of the irradiation and the beginning of the counting was kept constant at 25 sec. The use of the flow counter confirmed the belief that many surfaces emit low energy "delayed" electrons for periods varying from 30 sec to several minutes. Both the "delayed" electrons and the increased photosensitivity have been observed by other workers under different circumstances.[10] Of the substances examined for these "delayed" electrons, zapon lacquer is an emitter, whereas collodion and Lucite are practically non-emitters. Consequently, the silver foils were mounted on Lucite disks, for handling purposes, and were coated with 0.2 mg/cm^2 collodion films.

III. RESULTS

(A) Half-Lives

Irradiations were made at 2.6 Mev with a 200 μamp beam current, and initial activities of about 100 counts/sec resulted. Data were obtained by photographing the scaler and clock every five seconds over a period of about 300 sec. Statistical errors were reduced by adding corresponding points from separate decay curves. The decay curves for Ag^{107*} and Ag^{109*} are shown in Fig. 1. The half-life of Ag^{107*} is 44.0±1.0 sec and that of Ag^{109*} is 40.0±1.0 sec. Bradt, *et al.*,[7] measured half-lives of 44.3±0.2 sec and 39.2±0.2 sec, and Helmholz[8] assigned these to Ag^{107*} and Ag^{109*}, respectively. The direct measurements obtained in this experiment verify this assignment.

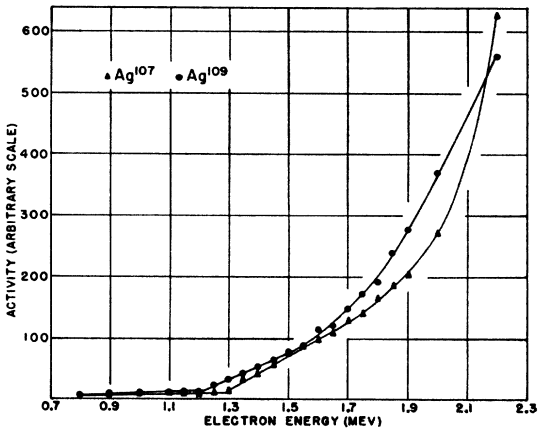

FIG. 3. Thick target x-ray excitation curves.

[10] M. L. Wiedenbeck and H. R. Crane, Phys. Rev. **75**, 1268 (1949).

(B) Excitation Curves

The thick target x-ray excitation curve is obtained by plotting the normalized activity as a function of the electron beam energy. Since the activity has a short half-life, the varying target current was weighted exponentially from the end of the irradiation period. Thus, all activities were normalized to infinite irradiation with constant current. For each isotope, several irradiations were made at each voltage, and the activities were averaged to reduce the statistical error.

Figure 2 shows the lower energy portions of the excitation curves for Ag^{107} and Ag^{109}, respectively. The thresholds in both cases are below 800 kev, although the data do not permit accurate location. The breaks in the curves indicate an activation level in Ag^{107} at 1.285 $\pm$0.018 Mev and an activation level in Ag^{109} at 1.210 $\pm$0.018 Mev. Figure 3 shows both excitation curves over the entire energy range investigated and emphasizes the 75-kev difference between the corresponding levels in the two nuclei. In considering the close similarity between the two nuclei in other respects, it is to be expected that such a small difference between the energy levels exists. The approximate over-all cross section (i.e., per electron incident on a thick gold target) at 1.4 Mev is of the order of 10^{-34} cm^2 for both isotopes. In Figs. 2 and 3, to convert *activity* to *over-all cross section*, multiply the ordinates by 4×10^{-36} cm^2.

These excitation curves agree with the early work of Feldmeier[2] in this laboratory but are contrary to that of Wiedenbeck.[4] This experiment is further confirmation that, as has been previously discussed,[3] one cannot obtain more than a few energy levels by x-ray excitation.

ACKNOWLEDGMENTS

We wish to express our appreciation to Professor A. C. Helmholz of the University of California for supplying the separated silver isotopes. Assistance in taking data and operating the electrostatic generator was generously contributed by E. J. Schillinger and T. F. Ruane.

PHYSICAL REVIEW VOLUME 82, NUMBER 4 MAY 15, 1951

Effect of Finite Nuclear Size on the Elastic Scattering of Electrons*

LOUIS K. ACHESON, JR.†
Physics Department, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received August 15, 1950)

The effect of the finite size of the nucleus on the elastic scattering of electrons with energies in the neighborhood of 20 Mev has been calculated for two simple spherical nuclear models: a uniform charge distribution, and a uniform shell charge distribution, both of radius $R=1.45\times10^{-13}A^{\frac{1}{3}}$ cm. An exact phase shift analysis has been made, the phase shifts differing appreciably from those for a point nucleus only in the $j=\frac{1}{2}$ state.

Phase shifts for elements of $Z=13$, 29, 50, and 79 have been plotted as a function of energy over the interval from 15 to 35 Mev, permitting the calculation of any desired cross section within this range. Representative curves of the ratio of the scattering cross section for the finite nucleus to that for a point nucleus have been plotted.

The difference in the scattering due to the two models is large enough so that accurate experiments might distinguish between them, the actual average nuclear charge distribution probably falling somewhere between these two cases. The ability to differentiate between the two models, however, depends on the accuracy with which nuclear radii are known.

I. INTRODUCTION

WHEN a beam of high energy electrons ($\sim$20 Mev) falls on an atom, a significant part of the scattering results from electrons which have actually penetrated the nucleus, so that the scattering cross section depends on the nature of the nuclear charge distribution. Previous calculations for lower energies have taken the nucleus to be simply a point charge. It is the purpose of this paper to calculate the effect of the finite nuclear size on the scattering of these high energy electrons. Two simple nuclear models are assumed: (1) a uniform spherical charge distribution, and (2) a shell charge distribution, with the charge distributed uniformly over the surface of the nucleus.

Rose[1] has already treated this problem by means of the Born approximation, which is valid for the light elements. Here exact results are obtained by means of a phase shift analysis.

For the energies of interest here, it is necessary to use the Dirac relativistic theory of the electron. Relativistic scattering theory, for spherically symmetric scattering centers, involves the solution of a pair of simultaneous first-order differential equations, the well-known Dirac

* This paper was supported in part by the joint program of the ONR and AEC.
† Now at Hughes Aircraft Company, Culver City, California.

[1] M. E. Rose, Phys. Rev. **73**, 279 (1948).