PHYSICAL REVIEW VOLUME 67, NUMBERS 3 AND 4 FEBRUARY 1 AND 15, 1945

The Nuclear Excitation of Silver and Cadmium

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(Received December 9, 1944)

The x-ray and electron excitation of silver and cadmium has been studied in the region from their thresholds to 3.3 Mev. The thick target x-ray excitation curve for silver shows the threshold to be 1.18±0.03 Mev and higher activation levels are found at 1.59, 1.95, 2.32, 2.76, and 3.13 Mev, respectively. The half-life of the metastable state of silver is 40.4±0.2 seconds. Both the thick target x-ray excitation curve and the electron excitation curve for cadmium indicate that the threshold for these processes is 1.25±0.03 Mev while other activation levels are found at 1.68, 2.08, and 2.56 Mev. The energy of the metastable level of cadmium, as determined from data on the absorption in aluminum of the conversion electrons emitted in the process, has been found to be 195 kev and the half-life of the metastable level is 48.7±0.3 minutes.

INTRODUCTION

NUCLEAR isomerism was first observed when it was found that three radioactive periods could be produced by the irradiation of bromine with slow neutrons.[1] Since there are only two stable isotopes of bromine, namely, ${}_{35}Br^{79}$ and ${}_{35}Br^{81}$, it was necessary to assign two of these periods to a single isotope.

It was pointed out by von Weizsacker[2] that such a condition may be explained by the assumption that there is a large difference of spin between the two states and hence the state of higher energy may exhibit a relatively long lifetime against γ-emission. In 1938, Goldhaber, Hill, and Szilard[3] found that the *stable* isotope In^{115} possessed such a metastable level which could be excited by fast neutrons and which decayed to the ground level with a period of 4.1 hours. Since this time, eleven stable nuclei possessing metastable states have been reported.[4]

The presence of a low lying metastable state in a stable nucleus affords a very accurate method for determining a series of the energy levels of that nucleus. Inasmuch as the transition from the metastable to the ground level is forbidden, because of the large difference in angular momentum, the direct transition from the ground state to the metastable state is just as strongly forbidden. Therefore, to reach the metastable state, the nucleus must first be raised to a higher activated level, the spin of which is intermediate between that of the ground and metastable states. The nucleus can then leave this activated level either by direct transition to the ground state or it may fall to the metastable level with a further change of spin, $l_m - l_a$, and the emission of energy, $h\nu_a - h\nu_m$. After the nucleus is in the metastable state it can only fall to the ground state with the emission of energy $h\nu_m$ and a large change of angular momentum, $l_g - l_m$.

Nuclei, in general, can be raised to the activated levels by inelastic collision with neutrons,[3] protons,[5] alpha-particles,[6] electrons,[7] and by the absorption of x-rays. The latter two processes afford more complete and accurate methods for studying the excitation and for the determining of the positions of the higher activation levels.

If x-rays are produced by a beam of monochromatic electrons striking a thin target, the intensity of a given isochromat, in the continuous x-ray spectrum thus produced, was shown, in the energy ranges concerned here,[8] to remain constant at accelerating voltages equal to or greater than the energy of this isochromat. Hence, one should expect the activity in a sample irradiated with thin target x-rays to rise quickly to a certain value when the threshold energy for the process is reached and then to remain essentially constant

[1] C. H. Johnson and F. T. Hamblin, Nature **138**, 504 (1936); A. H. Snell, Phys. Rev. **52**, 1007 (1937).
[2] C. F. von Weizsacker, Naturwiss. **24**, 813 (1936).
[3] M. Goldhaber, R. D. Hill, and L. Szilard, Phys. Rev. **55**, 47 (1939).
[4] For a recent reference list see: G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944)
[5] S. W. Barnes and P. W. Aradine, Phys. Rev. **55**, 50 (1939).
[6] K. Lark-Horovitz, J. R. Risser, and R. N. Smith, Phys. Rev. **55**, 878 (1939).
[7] G. B. Collins and B. Waldman, Phys. Rev. **57**, 1088 (1940).
[8] E. Guth, Phys. Rev. **59**, 325 (1941).

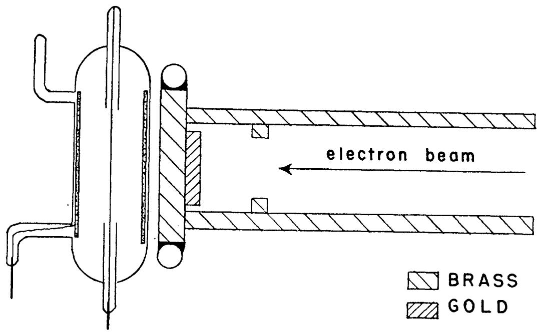

FIG. 1. Thick x-ray target arrangement with silver counter in bombardment position.

until a second activation level is reached, whereupon the activity will again rise in a similar manner. The positions of these sudden rises in the activity *vs.* accelerating potential curves then indicate the energy of the activated levels.

Similarly, as has been pointed out by Guth,[8] if we consider the thick target continuous x-ray spectrum as composed of a multitude of thin targets superimposed one behind the other, the activity should rise linearly with accelerating potential until another activation level is reached, whereupon the slope of the activity curve increases. The intersection of the two linear portions thus indicates the position of the activation level.

If the process is one of resonance absorption, the electron excitation curves should show sharp peaks when an activation level is reached and then fall to a lower value once this energy has been exceeded, similarly to the well-known excitation curves of Franck and Hertz for electrons striking an atom.

EXPERIMENTAL PROCEDURE

A. Silver

It had previously been found[9] that silver possesses a metastable state 93 kev above the ground level which decays with a half-life of 40 seconds. It has also been shown that this activity can be

[9] L. W. Alvarez, A. C. Helmholz, and E. Nelson, Phys. Rev. **57**, 660 (1940); G. E. Valley and R. L. McCreary, Phys. Rev. **56**, 863 (1939); A. C. Helmholz, Phys. Rev. **60**, 160 (1941); E. Segrè and G. T. Seaborg, Phys. Rev. **59**, 212 (1941).

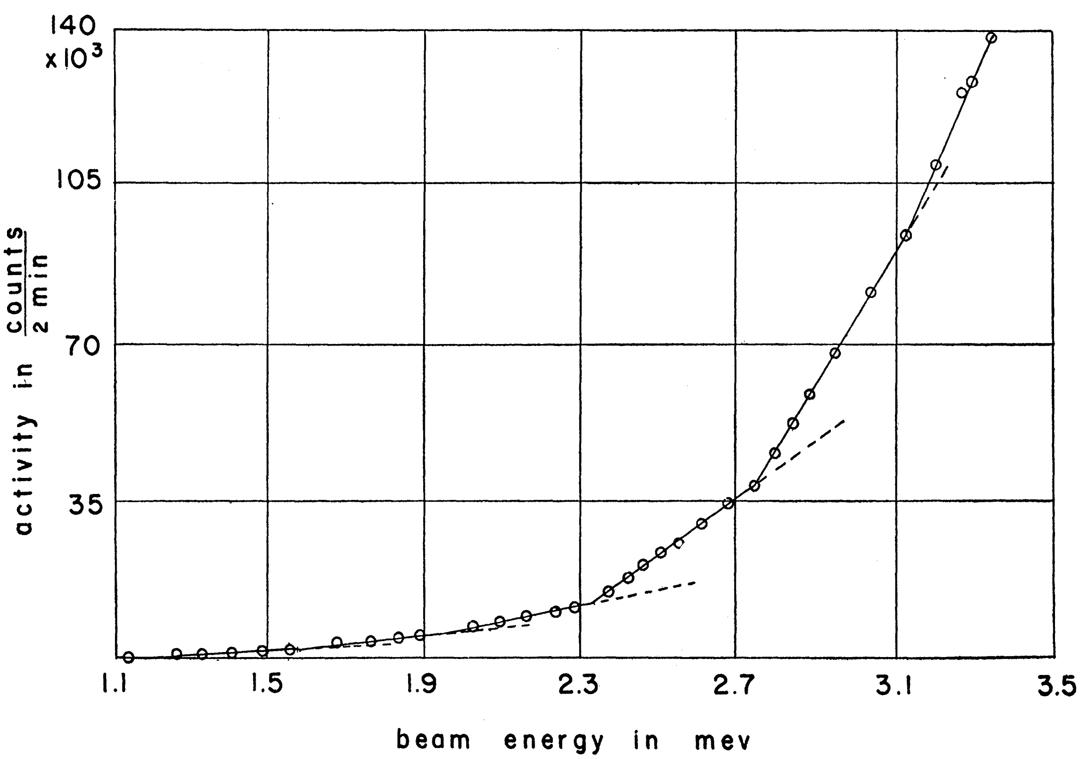

FIG. 2. Thick target x-ray excitation curve for silver. The positions of sudden changes in slope give the position of the energy levels which combine with the metastable state.

produced by direct x-ray bombardment of silver.[10]

In the present work, the x-rays were produced by a beam of electrons impinging on a gold target. The electrons were accelerated by a high pressure van de Graaff-Herb generator.[11] The sample of silver being irradiated formed the cylinder of a counter which was placed directly in front of the target as shown in Fig. 1.

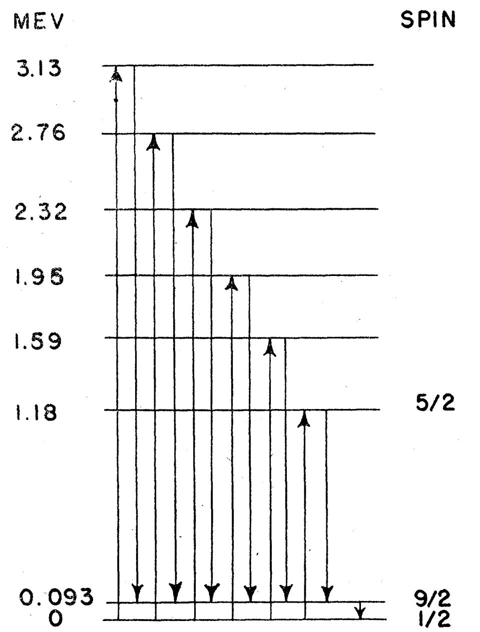

FIG. 3. Nuclear energy level diagram for silver showing the various transitions by which nuclei may reach the metastable state.

The counters used were self-quenching and were filled with an argon (90 percent)—ether (10 percent) mixture. It has been found that such a counter could be irradiated for several hours with very intense x-ray beams without showing a change in threshold or counting efficiency. Argon-alcohol counters, on the other hand, quickly deteriorate under the action of an intense x-ray beam.

In obtaining an excitation curve it is necessary to find the activity produced as a function of the accelerating voltage, keeping all other quantities which might influence the activity constant. For the work with thick target x-rays, the electron beam used was 200 microamperes, the irradiation time was fixed at two minutes, and the activity was taken as the number of counts above background during the two-minute period starting five seconds after the beam was turned off.

The curve thus obtained is shown in Fig. 2. It can be seen that the threshold, which represents the first activation level above the metastable state, is found at 1.18 Mev and higher activation levels, indicated by the sharp breaks in the curve, are found at 1.59, 1.95, 2.32, 2.76, and 3.13 Mev, respectively.

From these data it is possible to draw a nuclear energy level diagram for silver (Fig. 3) indicating the excitation and the subsequent decay of the excited levels combining with the metastable state.

Difficulties were encountered in observing the excitation of silver by direct electron bombardment since the energy of the conversion electrons emitted in the transition from the metastable to the ground state is very low (66 kev). These electrons are completely stopped by a very small thickness of material. As a consequence, it was necessary to find an arrangement by which the silver could be bombarded and then placed directly inside of a counter with as short a time delay as possible. To accomplish this, a counter was mounted on a large brass stopcock (Fig. 4) along with a ballast bottle filled with an argon-ether mixture at the same pressure as that in the counter. With this arrangement, the sample was placed in a cavity (*a*) in the inner part of the stopcock when at position (*b*). After the cavity was evacuated at position (*c*) by means of a forepump, it was turned to position (*d*). The cavity was then filled with the gas mixture to the same

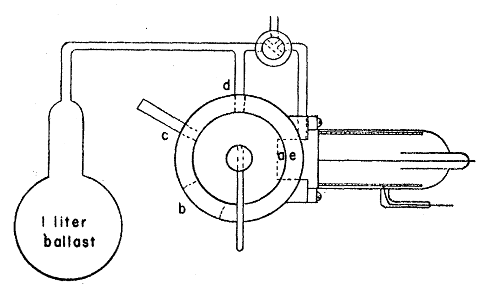

FIG. 4. Geiger-Müller counter mounted on a brass stopcock for admitting active sample to the inside of the counter.

[10] J. Feldmeier and G. B. Collins, Phys. Rev. 59, 937 (1941).

[11] This name seems appropriate for generators of the high pressure type since much of the early work in their development was done by Herb and his group.

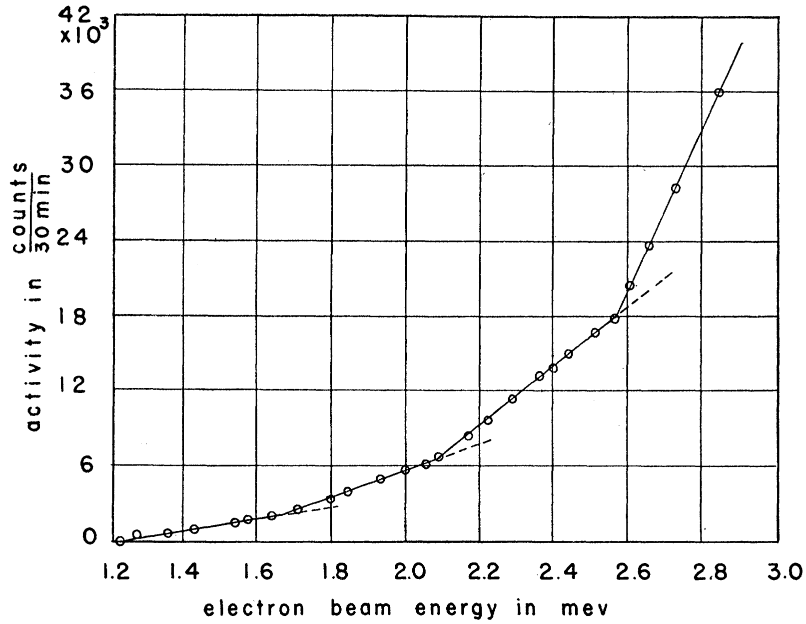

FIG. 5. Thick target x-ray excitation curve for cadmium.

pressure as the counter after which it was turned to position (*e*) within the counter. With this arrangement the sample could be gotten into the counter within two minutes after irradiation was stopped. Activity produced by the electron bombardment was observed but the complete excitation curve has not as yet been studied for this element.

The half-life of the metastable state was determined from a decay curve extending through six half-life periods with an initial activity of 8000 counts/15 seconds. These data give a value of 40.4±0.2 seconds for the half-life.

This metastable state may belong either to $_{47}Ag^{107}$ or $_{47}Ag^{109}$ both of which have spins of $\frac{1}{2}$ in the ground state. From the decay period and energy of the metastable state, this would imply a spin of 9/2 for the metastable state[12] and a probable spin of 5/2 for the level at 1.18 Mev.

[12] A. C. Helmholz, Phys. Rev. **60**, 415 (1941).

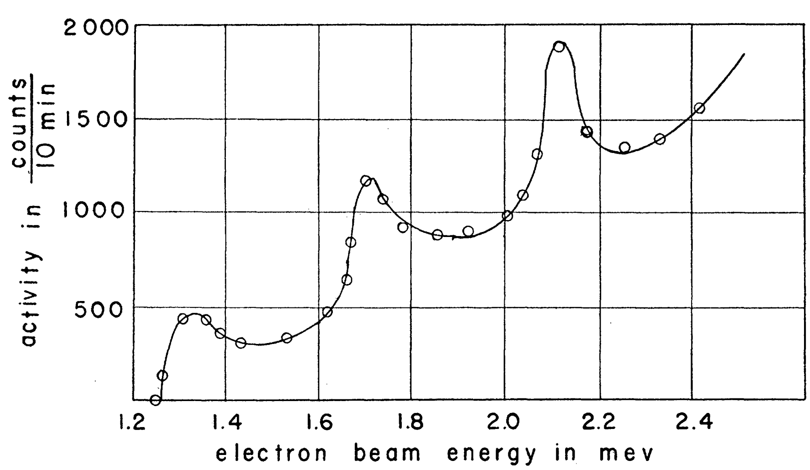

FIG. 6. Electron excitation curve for cadmium. The positions of sharp rises give the energy of the excited levels in the resonance absorption.

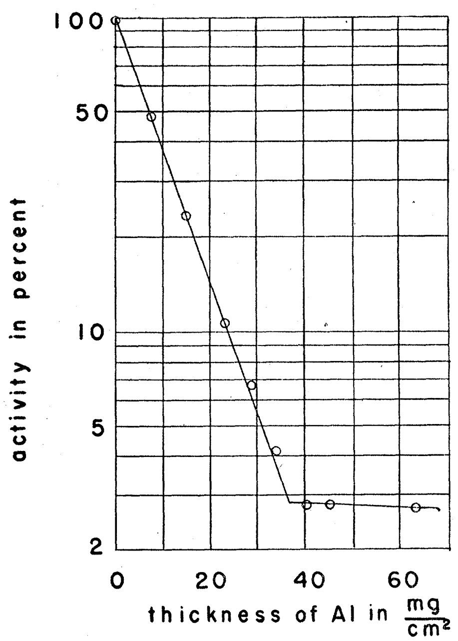

FIG. 7. Absorption curve for the conversion electrons emitted in the transition: $Cd^* \rightarrow Cd + \gamma$.

B. Cadmium

The fifty-minute period of cadmium[10,13] has been studied in a manner similar to that used with silver. The positions of the activated levels have been found from a thick target x-ray excitation curve. The activity was taken as the number of counts obtained during the first half-hour after irradiating a counter with a cadmium cathode for a time of ten minutes with a beam current of 250 microamperes. This curve is shown in Fig. 5 and as is seen, the threshold for this reaction, $Cd + \gamma \rightarrow Cd^*$, is 1.25 ± 0.03 Mev and higher activation levels are found at 1.68, 2.08, and 2.56 Mev, respectively. In the region of the threshold, the samples were irradiated for much longer times with beam currents up to 700 microamperes so that the activity of the cadmium would greatly exceed the normal background of the counter. These activities were then corrected to the proper value of irradiation time and beam current.

An electron excitation curve for cadmium was also obtained by bombarding thin samples of cadmium directly with the electron beam. The activity produced in the samples was measured by the counter previously described (Fig. 4). The excitation curve (Fig. 6) shows a series of rather sharp peaks superimposed on a continuous background. The positions of these peaks occur at the same voltages as the breaks in the thick target x-ray excitation curves. The relative sharpness of these peaks in the electron excitation curve gives further evidence that the process is one of line absorption.

The energy of the metastable state was also determined by measuring the absorption of the conversion electrons in aluminum foils. Several runs were taken at a constant accelerating voltage and with constant beam current with various thicknesses of aluminum between the cadmium and the counting region. The activity was thus found as a function of the thickness (Fig. 7). The energy of the metastable state is then the energy of the conversion electrons plus the binding energy of the K electrons of cadmium. The value thus found is 195 kev.

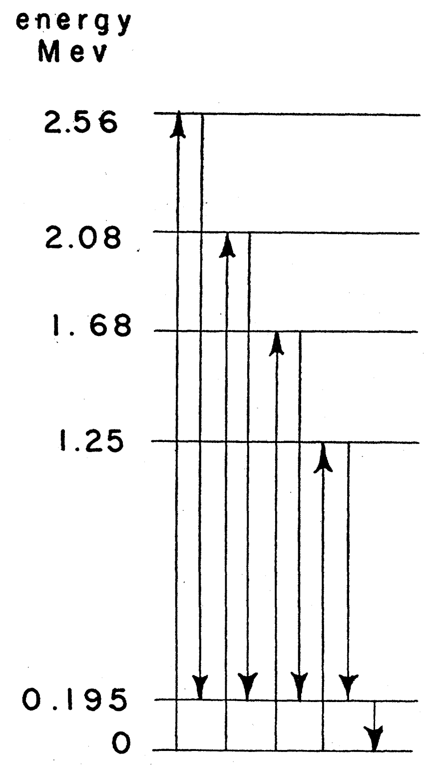

FIG. 8. Nuclear energy level scheme for cadmium.

[13] M. Dode and B. Pontecorvo, Comptes rendus **207**, 287 (1938); M. L. Wiedenbeck, Bull. Am. Phys. Soc. **19**, No. 3 (1944).

From these data one can draw a nuclear energy level diagram for cadmium (Fig. 8) showing the various energy levels combining with the metastable state.

The isotope of cadmium which possesses the metastable state can be either $Cd^{110, 111, 112, 113}$ since this activity has also been produced by Scherrer *et al.*[14] by the Cd $\gamma-n$ reaction. Of these, Cd^{110} can probably be eliminated in as much as material with this period cannot be grown from silver having the 22-second period.

DISCUSSION

It is of interest to notice that metastable levels were found for two "triads:" silver, cadmium, and indium;[15] and platinum,[16] gold,[17] and mercury.[18] It is very likely that the group, krypton,[19] strontium,[20] and rubidium, may form another such "triad."

The level schemes in the "triad," silver, cadmium, and indium, show that the spacing of these levels is approximately uniform in any one of the elements. A similar condition has been found to exist in the case of nitrogen.[21] However, it should be noted that nitrogen is among the light elements while the elements studied here are of intermediate weight. It is possible that with the extension of these excitation curves to higher energies the levels will converge as in the case of atomic spectra.

ACKNOWLEDGMENTS

The author wishes to express his thanks to Mr. V. C. Stock and Brother Camille, C.S.C., of the Physics Department Machine Shop for their aid in the construction of apparatus. It is also with pleasure that the author expresses his thanks and appreciation to Dr. Eugene Guth for his many helpful suggestions in the analysis of this work.

[14] O. Huber, O. Lienhard, P. Scherrer, H. Wäffler, Helv. Phys. Acta **16**, 228 (1943).

[15] B. Waldman and M. L. Wiedenbeck, Bull. Am. Phys. Soc. **17**, No. 5 (Nov. 1942); M. L. Wiedenbeck, Thesis on nuclear excitation of Indium. Both thick and thin target x-ray excitation curves and the electron excitation curve has been obtained for indium and will be reported in the near future.

[16] R. Sherr, K. T. Bainbridge, and H. H. Anderson, Phys. Rev. **60**, 473 (1941).

[17] Data on gold will be published in a forthcoming issue of Phys. Rev.

[18] F. A. Heyn, Nature **139**, 842 (1937); E. McMillan, M. Kamen, and S. Ruben, Phys. Rev. **52**, 375 (1937); M. L. Pool, J. M. Cork, and R. L. Thornton, Phys. Rev. **52**, 239 (1937).

[19] A. Langsdorf, Jr., and E. Segrè, Phys. Rev. **57**, 105 (1940).

[20] L. A. Dubridge and J. Marshall, Phys. Rev. **56**, 706 (1939).

[21] P. Comparat, Nature **153**, 720 (1944).