generator group for their cooperation in obtaining results especially suitable for the type of calculations used here, including their exceedingly careful elimination of other conceivable causes of the anomaly for which an interpretation is given above. We are also indebted to Professor Breit for sending us the values of the S-wave phase shifts corresponding to Yukawa meson potentials. This work was supported in part by the Office of Naval Research.

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An Investigation of Bremsstrahlung by Means of the Nuclear Isomerism of Indium*

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The metastable state of In^{115} has been used as a detector of a narrow energy band in the continuous x-ray spectrum produced by a monoenergetic electron beam on gold targets. The thin target x-ray isochromat ($h\nu = 1.04$ Mev) has been investigated in the neighborhood of the short wave-length limit. This isochromat is finite at the threshold and constant for at least 400 kev. This in agreement with Guth's theory and verifies the assumption that the excitation of In^{115*} is a line absorption. Both the thin target and thick target x-ray excitation curves for In^{115} have been obtained in the region from 1.0 to 2.6 Mev. The thin target curve exhibits a step-like character from 1.0 to 1.9 Mev. The thick target curve below 2.0 Mev exhibits straight line segments as expected from the thin target curve, but above 2.0 Mev there are no straight line segments, in good agreement with the thin target data and theory. Activation levels have been found at 1.04 ± 0.02 Mev and at 1.42 ± 0.02 Mev. The over-all cross section (per electron incident on a 34 mg/cm^2 gold target) is 10^{-34} cm^2 in the region of the threshold. Evidence is presented for the existence of a lower activation level between 0.8 and 0.9 Mev with an over-all cross section (for a similar target) of the order of 10^{-36} cm^2.

INTRODUCTION

THE x-ray excitation of the isomeric state of indium (In^{115*}) was first observed almost ten years ago.[1,2] The early work of Collins and Waldman[3] indicated that new information could be obtained about (a) the character of the continuous x-ray spectrum (bremsstrahlung) produced by a monoenergetic electron beam and (b) some nuclear energy levels of the excited nucleus. The latter is exemplified by the work of Waldman and Wiedenbeck[4] on indium and by Wiedenbeck[5] on many other elements.

The first conclusive evidence of nuclear isomerism in a stable nucleus was reported by Goldhaber, Hill, and Szilard.[6] They found that the 4.1-hour negative electron activity of indium could be produced by fast neutrons but not by slow neutrons; in fact, there seemed to be a threshold for the process. This activity was assigned to a metastable state of In^{115} excited by the neutron impact and designated by In^{115*}. They postulated that this metastable state can be reached by a spontaneous transition from a higher energy activation level, and that the negative electron activity may be the internal conversion electrons from the gamma-ray transition, In^{115*} to In^{115}. Lawson and Cork[7] have shown that the energy of the gamma-ray is 338 kev and the conversion coefficient is 0.5.

A. Activation by X-Rays

Pontecorvo and Lazard[1] produced In^{115*} by irradiation with x-rays of 1.85-Mev maximum

* The results of this paper were presented at the M.I.T. Accelerator Conference on June 8, 1948.
[1] B. Pontecorvo and A. Lazard, Comptes Rendus **208**, 99 (1939).
[2] Collins, Waldman, Stubblefield, and Goldhaber, Phys. Rev. **55**, 507 (1939).
[3] G. B. Collins and B. Waldman, Phys. Rev. **59**, 109 (1941).
[4] B. Waldman and M. L. Wiedenbeck, Phys. Rev. **63**, 60 (1943).
[5] M. L. Wiedenbeck, Phys. Rev. **67**, 92 (1945); Phys. Rev. **68**, 1 (1945); Phys. Rev. **67**, 267 (1945); Phys. Rev. **68**, 237 (1945).
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energy from an impulse generator. Independently, Collins, Waldman, Stubblefield, and Goldhaber[2] using x-rays from the Notre Dame electrostatic generator found the threshold for the x-ray excitation to be 1.35 ± 0.1 Mev. Later Waldman, Collins, Stubblefield, and Goldhaber[8] reported a more accurate threshold of 1.2 ± 0.1 Mev. Their excitation curve, i.e., activity *vs.* energy of electrons producing the x-rays, had a sharp break or change of slope at 1.55 ± 0.1 Mev, and they postulated the presence of a second activation level at this energy. Collins and Waldman[3] studied the excitation of indium by x-rays produced in a thin (23 mg/cm^2) gold target. This excitation showed a rise in activity at the threshold, followed by a flat plateau up to 1.55 Mev, followed by another sharp rise. Unfortunately, the errors were large in this experiment, and little confidence was placed in the results. The cross section was estimated to be 10^{-33} cm^2. Waldman and Wiedenbeck[4] carried the excitation to higher energies with a pressure electrostatic generator and found evidence for activation levels at 1.12 Mev, 1.55 Mev, 2.13 Mev, and 2.64 Mev. A decay curve for In^{115*} was followed for 24 hours, and the half-life was found to be 4.42 ± 0.02 hours. In 1943, Korsunsky, Walther, Ivanov, Zypkin, and Ganeko[9] published the results of their work on indium. They irradiated indium with x-rays up to 1.6 Mev produced in a thin (8.9 mg/cm^2) target of gold backed by a thick target of beryllium. The activity produced by the beryllium backing was subtracted from that produced by the composite target to give the activity caused by the thin gold. The threshold was found at 1.07 ± 0.05 Mev in good agreement with the Notre Dame value. However, their thin target excitation curve is a smooth curve showing neither plateaus nor straight segments. These results agree with the Bethe-Heitler theory, but this theory does not hold near the threshold.

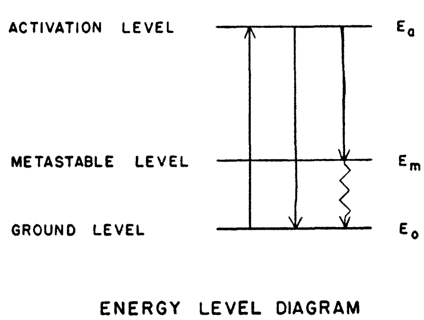

FIG. 1. Energy level diagram.

B. Activation by p, α, e, n, and d

Barnes and Aradine[10] produced In^{115*} by proton bombardment and estimated the cross section to be 10^{-29} cm^2 at 5.8 Mev. Lark-Horovitz, Risser, and Smith[11] produced this activity with 16-Mev alpha-particles. Collins and Waldman[12] excited In^{115*} with 1.3-Mev electrons and estimated the cross section to be about 10^{-33} cm^2. Waldman and Wiedenbeck[4] determined the excitation curve for this electron excitation. Recently Cohen[13] found evidence of a threshold for the neutron activation of In^{115*} at approximately 1 Mev and a cross section at 2.2 Mev of 3.6×10^{-25} cm^2. Following Guth's suggestion[14] of the possibility of inelastically scattering deuterons by a "polarization" process, Miller and Waldman[15] attempted to produce In^{115*} with 2-Mev deuterons. This activity was not detected thus setting an upper limit for the cross section for this process at 10^{-30} cm^2.

C. Activation of In^{113*}

Indium has one other stable isotope, In^{113}, which also exhibits nuclear isomerism.[16] Since its abundance is 4.5 percent, the 105-min. activity of In^{113*} is not easily detected in the presence of the 4.4-hour activity. Recently, Dunworth and Pontecorvo,[17] after irradiating indium with very intense 2-Mev x-rays, obtained the composite decay curve for both isotopes, from which the

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[11] K. Lark-Horovitz, J. R. Risser, and R. N. Smith, Phys. Rev. **55**, 878 (1939).

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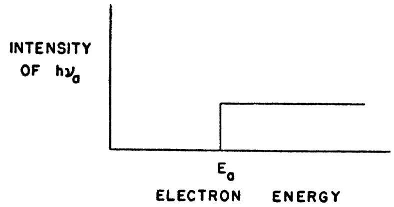

FIG. 2. Thin target isochromat.

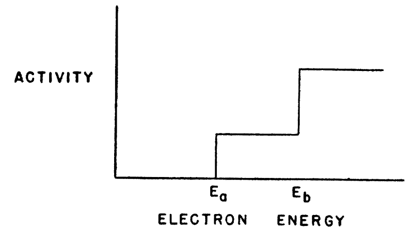

FIG. 3. Thin target excitation curve.

4.4-hour activity was subtracted leaving the 105-min. activity.

The aim of this investigation is to study the process of nuclear excitation by x-rays. This process consists of (a) the production of x-rays by monoenergetic electrons incident on a gold target and (b) the subsequent excitation of indium by these x-rays. In order to simplify the first process x-rays were produced in a thin gold target, however, thick gold targets were also used.

THEORY

Nuclear isomerism in a stable nucleus requires the existence of two energy states of the nucleus: one, the ground state; the other, the metastable state of measurable lifetime. This lifetime may be accounted for by a relatively large spin difference between the metastable and ground states. For a change of spin of 4 units, the lifetime may be from one second to many years and is a highly forbidden transition. The theory of the dependence of lifetime on energy and spin change has been reviewed by Wiedenbeck.[18] Since the transition from metastable to ground state is forbidden, so, also, is the inverse process. Thus, in order to excite a nucleus into its metastable level, it is necessary to raise it into an activation level by absorption of energy E_a, from which it can drop either to the ground level with emission of energy $h\nu_a = E_a$ or to the metastable level with emission of energy $E_a - E_m$ (Fig. 1).

Guth[19] has proposed an energy level diagram for indium in which the spin of the ground state is 9/2, the spin of the metastable state is 1/2, and the spin of the activation state is 5/2. Thus, the transition from metastable state to ground state involves a spin change of four units, whereas the transition from ground to activation state and that from activation state to metastable state both involve spin changes of two units.

The excitation of indium to the activation level may be (a) a line absorption (b) a Raman effect (c) a photo-effect. It is assumed to be a line absorption ($h\nu_a = E_a$) which is detected by virtue of the activity of the metastable level into which it may fall. If indium is irradiated with a continuous spectrum of x-rays, the activity is a measure of the intensity of that line in the spectrum equal to the activation energy. Since an isochromat is the intensity of a line of fixed energy ($h\nu_a$) as a function of electron beam energy E, the shape of the excitation curve in passing the activation energy reveals the shape of the corresponding isochromat.

The wave mechanical theory of the production of bremsstrahlung in the non-relativistic region has been given by Sommerfeld,[20] Sommerfeld and Maue,[21] and Weinstock[22] and confirmed experimentally by Nicholas,[23] Kulenkampff,[24] and the Stanford group under Kirkpatrick.[25] In the relativistic region the Bethe-Heitler theory applies

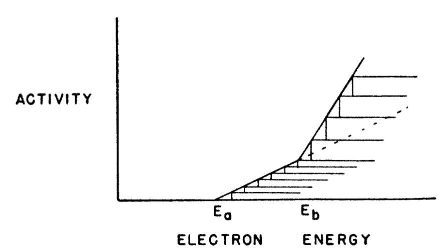

FIG. 4. Thick target excitation curve.

[18] M. L. Wiedenbeck, Phys. Rev. **69**, 567 (1946).
[19] E. Guth, Phys. Rev. **59**, 325 (1941).

[20] A. Sommerfeld, Ann d. Physik **11**, 257 (1931).
[21] A. Sommerfeld and A. W. Maue, Ann. d. Physik **23**, 589 (1935).
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[25] K. Harworth and P. Kirkpatrick, Phys. Rev. **62**, 334 (1942).

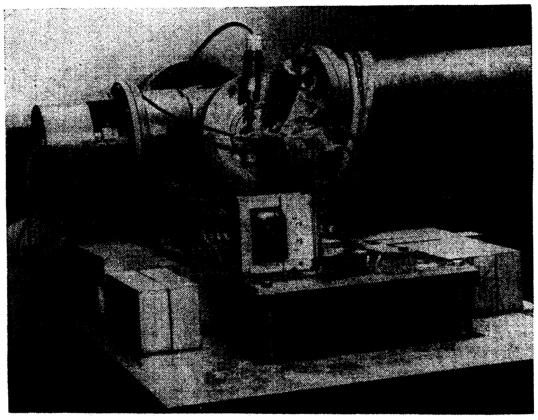

FIG. 5. Rocking target assembly.

within the Born approximation. Since it breaks down at the short wave-length limit (i.e., threshold) Guth[19] has calculated a correction factor to be applied at the threshold. This results in an isochromat which is finite at the threshold and independent of electron energy E in the immediate vicinity of the threshold. His calculations show that an isochromat of $h\nu_a = 1.1$ Mev should be constant within 2 percent if E is raised from the threshold to 1.4 Mev.

In the excitation of indium by thin target bremsstrahlung, the energy of the activation level is the energy of the isochromat $E_a = h\nu_a$. As the beam energy is increased, this isochromat should remain constant (Fig. 2), and, consequently, the excitation curve should remain constant. If indium has a second activation level at a higher energy E_b, a second isochromat, $h\nu_b = E_b$, will be detected; and it should have the same flat character. The excitation curve should show this isochromat superimposed on the first; or, in other words, a step-like curve consisting of two plateaus (Fig. 3).

In the excitation of indium by thick target x-rays, the shape of the excitation curve reveals the shape of the thick target isochromat. If the thick target is assumed to be a summation of thin targets, then it is reasonable to assume that the thick target isochromat will be an integral of the thin target isochromat. The excitation curve should have a positive slope from the threshold up to the energy E_b, at which point the height of the infinitesimal thin target steps increases, resulting in a more positive slope as shown in Fig. 4.

If Φ is the cross section for the production of quanta of energy $h\nu_a$ by one electron of energy E' in a target of thickness dx and N atoms/cm^3, then the number $n(h\nu_a,E')$ of quanta produced in a thick target is given by Eq. (1).

$$n(h\nu_a,E')_{\text{thick}} = \int \Phi N dx = \int_{h\nu_a}^{E'} \frac{\Phi N dE}{(-dE/dx)}. \quad (1)$$

Assuming Φ and $(-dE/dx)$ are constant over the energy interval $h\nu_a$ to E' then (1) can be integrated

$$n(h\nu_a,E')_{\text{thick}} = \frac{N\Phi}{(-dE/dx)}(E'-h\nu_a). \quad (2)$$

Thus the thick target isochromat is a straight line of positive slope.

EXPERIMENTAL PROCEDURE

A. Irradiation

The thin target x-rays were produced by bombarding a gold foil 34 mg/cm^2 thick with the electrons accelerated by the Notre Dame Pressure Electrostatic Generator. The activity produced in the indium was sufficiently low that it was advantangeous to place it close to the gold.

The fact that the electrons after passing through the gold could activate as well as melt the indium presented a serious difficulty. A strong magnetic field was placed between the

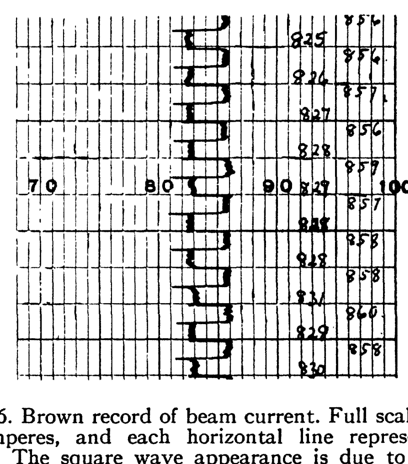

FIG. 6. Brown record of beam current. Full scale is 125 microamperes, and each horizontal line represents 20 seconds. The square wave appearance is due to the reflection of the incident electrons by the gold foil. The small numbers at the right are the estimations of the current for integration.

gold and the indium to prevent the electrons from reaching the indium. This was unsuccessful because the electrons were deflected before reaching the gold in spite of the fact that a magnetic shield was used. A second attempt consisted in placing the indium on the outside of a long evacuated thin-walled aluminum cylinder, coaxial with the beam, the gold foil forming one base of the cylinder, the electron collector forming the other base. This would allow the electrons to be collected at some distance from the indium which was placed near the gold end of the cylinder. The gold scattered enough electrons so that the walls of the cylinder became hot and melted the indium. A water jacket placed around the aluminum cylinder prevented this, but the indium activity was then too small, and the x-rays produced in the aluminum could not be taken into account.

The method finally used was a subtraction process in which the electrons passing through the gold were absorbed by a carbon disk one-half inch thick backed by a one-sixteenth-inch sheet of aluminum. Two such carbon-aluminum absorbers were placed in a water cooled mount with the gold foil on the face of one and indium foils on the backs of both. An electromagnet, energized automatically, rocked first one and then the other of these absorbers into the electron beam with a twenty-second period (Fig. 5). The activity of the indium irradiated by the x-rays produced in the carbon was subtracted from the activity caused by the x-rays produced in the gold plus carbon. The irradiation times were measured by Standard Electric Timers controlled by micro-switches on the rocker, and both samples received the same irradiation time within one percent. The cross-irradiation, i.e., the irradiation of the non-exposed indium foil by the x-rays produced in the exposed target assembly, was negligibly small.

A criterion for a "thin" target is that activity be proportional to thickness. When the 34-mg/cm² gold foil was replaced by a 20-mg/cm² foil, the activity was decreased to approximately 60 percent.

In the thick target experiment the x-rays were produced by stopping the electron beam in a 1.6-mm gold target at the bottom of a copper Faraday cage. The indium foils were placed on the outside of this cage in line with the beam.

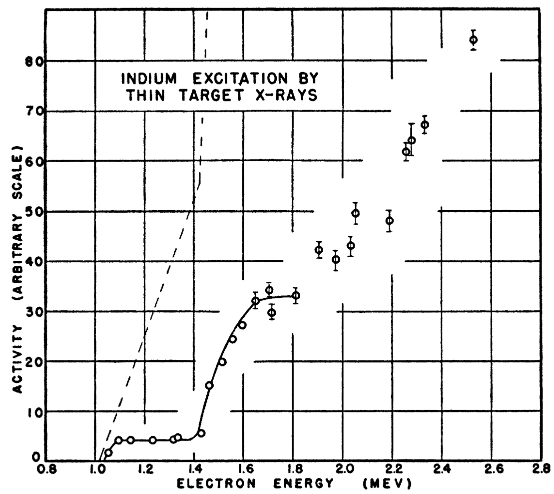

FIG. 7. Thin target excitation curve for indium[115]. Errors in activity and in voltage are less than size of circles unless otherwise indicated. To convert *activity* to *over-all cross section* multiply ordinate by 2×10^{-35} cm² for 34-mg/cm² gold target. Dotted curve is first portion of thick target curve (Fig. 8) to same scale.

B. Counting

Pure indium metal was rolled into sheets of thickness 0.01 inch, and disks of diameter $\frac{15}{16}$ inch were punched from this sheet. This thickness (185 mg/cm²) is greater than the range of the conversion electrons to be detected. The activity of the two indium foils was measured simultaneously by two similar thin end-window Geiger tubes and scalers. Each foil was counted first on one scaler for 1000 seconds and then on the other scaler for 1000 seconds. This cross-over technique has the advantage that it is unnecessary to know the sensitivity or the geometry of each counter before subtracting the data. It is only necessary that these factors remain constant during the course of the experiment. It can be shown that the difference in activity of the two foils is proportional to the difference between the geometrical mean of the counts from one foil on both scalers and the geometrical mean of the counts from the other foil. The proportionality constant depends on the irradiation time and the delay times as well as the sensitivities of the Geiger tubes. These times were held constant and the same Geiger tubes were used for the entire experiment.

This cross-over counting scheme was checked by irradiating both indium foils with x-rays from the carbon absorbers only—that is, the gold foil was removed from its usual place. The difference between the indium activities was zero within the statistical counting errors.

For the thick target experiment the indium foils were counted with one of the counting units described above.

C. Current

The electrons accelerated by the electrostatic generator passed through a slit system consisting of two circular apertures, the first a $\frac{1}{4}$-inch hole, the second a $\frac{5}{16}$-inch hole, about 9 inches apart and through a one-mil aluminum window onto the rocking target assembly. The current to the target must be measured by a low impedance device since the ionization of the air presents a relatively low impedance leakage path to ground. A multirange sensitive microammeter has a resistance of about 2000 ohms, and this introduces an error of about 10 percent in measuring the target current. This difficulty was overcome by using a Brown recording potentiometer (three-millivolt full scale) to measure the voltage developed by the target current in flowing through a small precision resistor of about 25 ohms. A further advantage of this device is the record obtained. As a result of the motion of the rocker and the reflection of the electrons from the gold foil, it is quite apparent which target is being irradiated at a particular time (Fig. 6).

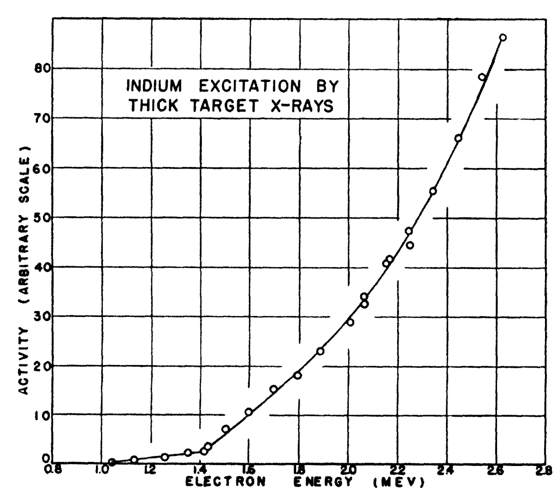

FIG. 8. Thick target excitation curve for indium^{115}. To convert *activity* to *over-all cross section* multiply ordinate by 3×10^{-24} cm^2.

The record of the current to each target was integrated by estimating each ten-second interval and summing for each target to obtain the total charge incident on that target. The charge for the gold-carbon target was adjusted for the reflection mentioned above. The mean counts obtained from each indium foil were normalized by the appropriate charge before subtracting the data.

For the thick target experiment the Brown record was integrated with a planimeter whose accuracy was checked on a standard area and found to be ±0.3 percent. The counts obtained from the foil were normalized by this charge.

D. Voltage

The energy of the electrons depends on the potential of the high voltage terminal of the electrostatic generator. This potential was measured by a null type generating voltmeter in which the electric field resulting from the terminal is balanced by a field produced by a battery. The battery voltage was measured to 0.1 percent by a potentiometer. The off-balance of the terminal potential was detected by a gated vacuum tube voltmeter and recorded on an Esterline-Angus recorder. With this device a change in sphere potential of ±5 kv can be detected. The voltmeter was calibrated[26] by determining the photodisintegration thresholds of beryllium and deuterium and accepting Stephens'[27] values of 1.63 and 2.187 Mev, respectively. These values have an accuracy of about ±20 kev so the absolute accuracy of our voltmeter is no better than this.

The output of the voltmeter operates a stabilizing control of the belt charging supply. This stabilizer consists of two parts, a variable impedance circuit similar to Hanson's[28] to compensate for fast changes and a motor driven Variac to compensate for slow changes. With this device a stability of ±5 to 10 kv can be maintained for long irradiations.

[26] B. Waldman and W. C. Miller, Phys. Rev. **74**, 1225 (1948).
[27] W. E. Stephens, Rev. Mod. Phys. **19**, 19 (1947).
[28] A. O. Hanson, Rev. Sci. Inst. **15**, 57 (1944).

RESULTS AND DISCUSSION

From the above discussion it can be seen that the errors, except statistical errors in counting, have been reduced to less than one percent. For the thin target experiment where the activity is low, these statistical errors are large. These are increased by the subtraction process so that the total errors are between four and ten percent (standard deviation). For the thick target experiment, the statistical errors are not greater than 2.5 percent and in most cases are about 1 percent.

A. Thin Target

Figure 7 is a plot of the thin target excitation in the region from 1.0 to 2.6 Mev. This shows the sharp threshold and a plateau followed by another sharp rise and a subsequent plateau. The flat portion of this curve indicates that the thin target x-ray isochromat is also constant, at least within 400 kev of the threshold. This is in excellent agreement with Guth's theory and verifies his assumption that *the excitation of indium is a line absorption.* The threshold is at 1.04 ± 0.02 Mev, and the sharp rise indicates an activation level at 1.42 ± 0.02 Mev. These values are lower than those of Waldman and Wiedenbeck[4] (1.12 ± 0.03 and 1.55 ± 0.03 Mev, respectively) because of the lower background counters (8 counts per minute) used in this experiment. The activity just above threshold would not be detected with higher background counters. Above 1.9 Mev the data do not warrant drawing a curve. There is an indication of other steps, but it is not strong. Possibly there are many levels lying close together which cannot be resolved by the method used in this experiment. Or perhaps the thin target isochromat is not flat for more than 500 kev. If it does not remain flat, the sharp rises due to other activation levels would be somewhat masked.

The over-all cross section (i.e., per electron incident on a 34-mg/cm² gold target) at the first plateau is 10^{-34} cm² within an order of magnitude. This over-all cross section σ is the product of two factors

$$\sigma = n(h\nu_a,E)_{\text{thin}}\cdot\sigma_{h\nu_a}, \tag{3}$$

where $n(h\nu_a,E)_{\text{thin}}$ is the number of quanta of energy $h\nu_a$ produced by one electron of energy E in a target of thickness dx and N atoms/cm³, and $\sigma_{h\nu_a}$ is the cross section for the production of the metastable nuclei by a quantum of energy $h\nu_a$. The number of 1.04-Mev quanta, $n(h\nu_a,E)$, as given by Guth[19] is

$$n(h\nu_a,E)_{\text{thin}} = A\frac{Z^2r_0^2}{137}\frac{d(h\nu)}{h\nu_a}Ndx, \tag{4}$$

where $A=3.44$ at 1.1 Mev and $d(h\nu)$ = the width of the level. Since $n(h\nu_a,E)$ is a linear function of the target thickness dx (for a thin target), the over-all cross section, σ, is also a linear function of the x-ray target thickness. Using this value of σ Guth has calculated the width of the 1.04-Mev activation level to be 4 millivolts. Using Eq. (4) one finds that the number of quanta of energy 1.04 Mev in a 0.004-ev width is 10^{-12}. Thus $\sigma_{h\nu_a}$ is of the order of 10^{-22} cm², a value to be expected for a resonance process.

The experimental verification of Guth's theory (Eq. (4)) permits one to calculate the number of 1.04-Mev quanta per incident electron in the energy range 1.0 Mev to 1.4 Mev. This can be extended to thick targets by Eq. (1). In order to determine numbers of quanta of energy other than 1.04 Mev, the slowly varying factor A in Eq. (4) must be evaluated.

B. Thick Target

Figure 8 is a plot of the thick target excitation in the same energy region. As would be expected from the thin target curve and Eq. (2), this excitation curve is a straight line of positive slope from the threshold at 1.04 ± 0.02 Mev to 1.42 ± 0.02 Mev. At this point there is a sudden change of slope corresponding to the sharp rise in the thin target curve. Above this energy the evidence for straight line portions is no more striking than that for more steps in the thin target curve. There are three reasons why one should not expect more straight line segments: (a) the stopping power $(-dE/dx)$ in Eq. (1) is not constant and independent of electron energy in the region above 2 Mev; (2) the thin target isochromat may not be independent of electron energy for more than 500 kev, and the integration of Eq. (1) would not yield a straight line of positive slope; (3) there may be many levels lying close together which cannot be resolved. Thus, even if there were no levels above 1.42 Mev, and even if the thin target isochromat were completely independent of energy, *one cannot expect a straight line excitation curve above 2 or 2.5 Mev.*

The cross section for the thick target excitation is given by an expression similar to Eq. (3) where $n(h\nu_a,E)_{\text{thin}}$ is replaced by $n(h\nu_a,E')_{\text{thick}}$ from Eq. (2). In the region where the thick target excitation is a straight line, the ratio of the thick target cross section to the thin target cross section is

$$\frac{\sigma_{\text{thick}}}{\sigma_{\text{thin}}}=\frac{n(h\nu_a,E')_{\text{thick}}\cdot\sigma_{h\nu}}{n(h\nu_a,E)_{\text{thin}}\cdot\sigma_{h\nu}}.$$

$$=\frac{\int N\Phi dx}{N\Phi\Delta x}=\frac{E'-h\nu_a}{(-dE/dx)\Delta x}, \quad (5)$$

where Δx is the thickness of the thin target. Using the average value of the stopping power in the region from 1.0 to 1.4 Mev of 10^7 volts/cm and $(E'-h\nu_a)$ equal to 400 kev, one finds this ratio should be about 19. A portion of the thick target excitation curve is plotted (dotted line) in Fig. 7 to the same scale as the thin target excitation. At 1.4 Mev the ratio is about 11, which is good agreement with theory when one considers the difference in angular distribution of the x-rays from thick and thin targets.

C. Lower Activation Level

Since the completion of the above experiments, further attempts were made to activate indium below 1 Mev. Five-hour irradiation with a 100 microampere beam of 880-kev electrons on the thick gold target resulted in very weak activity (twice background) of approximately 4.4 hours half-life. Correspondingly higher activity was found at 930 kev. The activity at 800 kev was not greater than 10 percent of background. This is an indication of another activation level below 1.0 Mev, and it may be the level at 873 kev reported by Lawson and Cork.[7] Assuming that this level is at 873 kev, one can estimate the cross section for thin target x-rays using the method of Eq. (5). This results in an over-all cross section of the order of 10^{-36} cm^2 per electron incident on a 34 mg/cm^2 gold target. Activation in this energy region is being investigated at the present time.

D. Self-absorption

Since the excitation of indium is a line absorption, one might expect to observe self-absorption. This was attempted using indium absorbers up to 1-cm thick. Replacing indium by a neighboring element, tin, resulted in an equivalent absorption. Thus, the absorption in indium can be completely accounted for by the usual Compton and photoelectric effects.

The very weak self-absorption is due to the large doppler width (0.7 ev) as compared to the radiation width (0.004 ev). This point has been discussed by Guth.[19]

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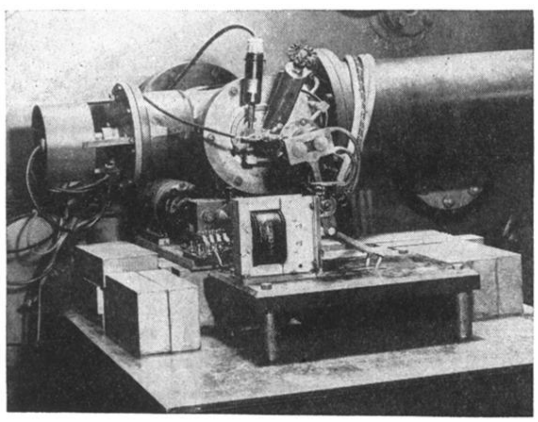

FIG. 5. Rocking target assembly.