NEW ISOMERIC TRANSITIONS OF SHORT LIFE IN GOLD, MERCURY AND THALLIUM

by

Arne Henrikson, M.Sc.

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SUMMARY

A NaI scintillation spectrometer is employed for the measurement of gamma-ray energies, and thereby the identification of short-lived isomeric transitions in gold, mercury and thallium.

Gamma rays arising from the positron decay of Co^{56} have energies 0.85, 1.26, 1.82, 2.12, 2.65 and 3.27 Mev with relative intensities 1, 0.55, 0.22, 0.06, 0.12 and 0.08 respectively. A tentative level scheme is proposed.

An isomeric transition in Tl^{197} (0.54 ± 0.01 sec.), is assigned on basis of thresholds for protons on Hg and Tl. The single gamma at 384 ± 6 kev is measured using a modified Hofstadter technique. The total-conversion coefficient of 2.7 and lifetime-energy relation point to M3 multipole radiation.

$Au^{191-193}$ (2.0 ± 0.3 sec.; no gammas observed) is observed by the same procedure.

Hg^{194} (0.40 ± 0.06 sec.; gammas at 134 ± 4 and 48 ± 4 kev) is assigned from similar thresholds on Au and Hg targets. The lifetime-energy relation labels the higher energy gamma as M3 or E3.

The gamma rays from Pb^{201m} and Pb^{202m} have been redetermined as 0.62 ± 0.02 and 0.83 ± 0.02 Mev respectively.

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Some of the early experiments of Drs. S. W. Breckon and W. M. Martin, showing indications of short-lived activities, led the author to study the region round gold and mercury. Appreciation is expressed for the communication of this information.

Many thanks are due Mr. R. H. Mills for his willing aid in carrying out the cyclotron bombardments. Thanks are also expressed for the use of the time-base unit built by Mr. Mills.

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INTRODUCTION

The work described in this thesis is concerned with the measurement of gamma-ray energies with a NaI scintillation spectrometer and thereby, the identification of new isomers produced in gold, mercury and thallium by proton bombardment in the McGill cyclotron.

Soon after Breckon and Martin[1] had set up their equipment for the study of short-lived radioactivities, survey experiments indicated unknown activities in several elements under proton bombardment. When gold or platinum was irradiated at increasing energies, the period, which at low energies was of the order of 7 seconds, seemed to become shorter. However, the results of this preliminary experiment were considered inconclusive due to trouble with the equipment used. These elements were not investigated further until the present time.

In his investigation of isomeric transitions in thallium and lead, Hopkins[2] observed some evidence of a new short activity when mercury was bombarded.

In the shell model of the nucleus, the region round gold, mercury and thallium may be expected to contain many isomeric states since there are energy states of relatively high angular momentum. The decay from such excited states is delayed by the large spin change that is necessary in order to bring the nucleus to a lower energy level. If the lifetime is sufficiently long to be measured, such states are called isomeric states. Many isomers are already known in this region. The above facts and ideas led the author to investigate further the evidence of short-lived isomeric states in gold, mercury and thallium.

In the investigation of the short-lived activities, use was made of the rapid-target-extractor described by Breckon and Martin.

The measurement of the gamma-ray half-life was obtained by the counting-rate-meter method described by the same authors. For the energy determinations two methods are available: (a) the pulse-height distribution may be studied by means of a single-channel analyzer; and (b) the pulses from the amplifier may be displayed on the oscilloscope and the pulse height spectrum measured directly from photographs. Method (b) has been modified to give higher accuracy and greater ease of analysis than the original Hofstadter[3] method.

In order to make an unambiguous assignment of the multipole order of the radiation detected, the total-conversion coefficient of the short-lived gamma ray from Tl^{197} was measured. This was accomplished by a method in which the conversion coefficient was measured by comparison with that of Cs^{137}. In this way several factors which by themselves would be difficult to measure, may be neglected without causing very large errors.

In the tests of the linearity of pulse against energy of the γ-ray in the spectrometer, sources of Cs^{137}, ThC" and Po-Be were used. However, it was felt desirable to have a single source which would combine the advantages of several calibration points, a high energy gamma ray, and easy availability. For these reasons, it was decided (as an alternative) to calibrate the spectrometer with the gamma-ray spectrum of Fe^{56} which arises from the positron decay of Co^{56}. The energies of the rays observed are 0.85, 1.26, 1.82, 2.12, 2.65 and 3.27 Mev. Relative intensities have been observed, and a tentative level-scheme proposed.

When Hg was bombarded in the cyclotron at fairly low energies and Tl at high energies, a new short-lived gamma activity was produced. This activity has been assigned from threshold measurements to an isomeric state in Tl^{197}. The half-life is measured as 0.54 ± 0.01 seconds and its energy is 384 ± 6 kev. Lifetime-energy relations label the transition

as M3 or E3. However, measurements of the total-conversion coefficient indicate that the transition is either M3 or M4. Thus, an M3 assignment would be consistent with the two results.

Bombardment of gold at energies greater than 25 Mev produced another new gamma emitting isotope. From threshold measurements on gold and mercury this has been assigned to Hg^{194}. The half-life is 0.40 ± 0.06 seconds and the energy is 134 ± 4 kev. In this case another gamma ray of 48 ± 4 kev appears to be associated with the higher energy transition. Lifetime-energy relations label the 134 kev gamma as either E3 or M3. No measurement of the internal-conversion coefficient was possible in this case.

When platinum was bombarded at low energies, another activity with a half-life of about 2 seconds was produced. This activity was also produced from a gold target irradiated at 80 Mev. However, no assignment has been possible and no gamma ray associated with this period has yet been observed. It is only possible to say that it probably arises from an isotope of gold of mass less than 193.

In the course of the investigation, the energies of the isomeric transitions in Pb^{201} and Pb^{202} have been redetermined.

DESCRIPTION OF THE APPARATUS

A block diagram of the essential features of the equipment is given in Figure 1. Not shown are a second counting head, amplifier, scale-of-8, and scaler which permit counting at two different bias levels, or with the beta and gamma counters simultaneously.

In the studies on short-lived activities, the rapid-target-extractor was used. This unit, designed and constructed by Drs. S.W. Breckon and W.M. Martin[1], moves the target from the bombardment position in the cyclotron tank to a position in front of the counters in about one-fifth second. The construction and operation of this unit has been treated in detail by these authors.

The radiation detectors consist of a NaI (Tl) gamma-ray counter, and a stilbene-crystal beta counter. The NaI crystal, a cylinder 1 inch diameter and 1 inch long, is mounted in an aluminum cup and surrounded with dried mineral oil. The aluminum cup is fitted with an O-ring to make an oil-tight seal against the face of the photomultiplier tube. The stilbene crystal is in the shape of a truncated cone 1-1/2 inches long and with the small end (1/2" diameter) facing the target. Each crystal is mounted on the end of an RCA 5819 photomultiplier tube in which the light pulse produced in the crystal by the capture of a gamma ray or a beta particle is converted into an electrical pulse. A pre-amplifier, mounted directly behind the photomultiplier tube, consists of a pulse inverter followed by a cathode follower matched to the long cable leading up to the tunnel where the main amplifier is located. The main amplifier is an Atomic Instruments Corp., model 204C, which is a commercial model of Jordan and Bell's A1 linear amplifier[4].

The equipment used for the half-life measurements is that described by Breckon and Martin. The output of the amplifier goes through a fast scale-of-8 to a counting-rate meter, the output of which is applied to the plates of a Dumont 241 oscilloscope. The sweep voltage for the oscilloscope is provided by a time-base generator designed and built by Mr. R.H. Mills. This provides a time-base variable from several milliseconds to about 30 seconds in length.

The pulse shaper and brightener, the bias-attenuator-limiter (pulse clipper) circuit, the Los Alamos 1000 amplifier and the single-channel analyser (differential discriminator) are used in the measurement of the energy of the gamma rays.

The pulse shaper and brightener circuits are from a design due to Watkins[5]. Boley and Zaffarano[6] and Hopkins[2] have used this circuit in a running-film method for energy determinations. In the present experiment the pulse shaper was used to give a clearer picture of the pulse height distribution than if the amplifier output had been displayed directly. The essential part of the pulse shaper is a condenser which is charged up through a diode from a cathode follower to the peak value of the pulse. The same pulse, delayed by 2 microseconds, and amplified, discharges the condenser. The result is a flat topped pulse, 2 microseconds in duration, whose amplitude is very nearly equal to that of the input pulse. This circuit is linear over a range of pulse heights from about 2 to 105 V output.

The brightener provides a sharp pulse about 1 microsecond in duration, either positive or negative, delayed by 1/2 microsecond, which may be applied to the brilliance control of the cathode ray tube to

brighten the top of the squared pulse for running film analysis. It has not been used in this experiment and will not be referred to again.

The bias-attenuator-limiter circuit (pulse clipper) was designed and built by Dr. W.M. Martin. It has these three functions: (i) to subtract an accurately known voltage from the pulse distribution so as to display the rest on an expanded scale; (ii) to give an accurate attenuation ratio of 1, 2, 4, or 8; and (iii) to limit the pulse amplitude to a value greater than that required for full scale deflection on the scope, but not large enough to overload the following amplifier.

The LA 1000 amplifier, a circuit borrowed from Elmore and Sands[7], supplies a push-pull output to drive directly the plates of the Tektronix model 513D oscilloscope. This amplifier is linear for output pulses of 0 to over 150 volts amplitude and has a gain of approximately 8.

The single-channel analyser, or differential discriminator, is of fairly standard design, with the exception of the "window amplifier" which is from a design due to Francis et al[8]. The input circuit consists of a biased amplifier, the bias of which is obtained from an accurately calibrated voltage divider. The resistances in this divider have been adjusted to 0.05% accuracy. The setting of the bias determines the channel position of the analyser. The pulse-height spectrum above this bias level is amplified and limited so that a ten volt interval is expanded to about a hundred volts. Two discriminators, one a Schmidt type trigger circuit, the other a univibrator, are set on this amplified section of the distribution with bias values such that the Schmidt trigger circuit will be triggered by

a lower amplitude pulse than the univibrator. The output of these two discriminators are then combined in an anti-coincidence circuit in such a way that an output is obtained only if the Schmidt circuit alone is fired. The above "window amplifier" makes the channel width much less dependent on the stability of the setting of the discriminators, than if they had been set only a volt or less apart on the unamplified pulse-height distribution. The effective channel width used in this experiment was approximately 0.7 volt.

The remaining parts of the apparatus, such as the high-voltage supplies, other power supplies, scalers and oscilloscopes are standard units and need no explanation.

EXPERIMENTAL METHOD

The target to be bombarded was mounted in the target holder of the target-extractor-unit, and moved ahead into the bombarding position by means of the probe controls. It was then irradiated for periods of from 0.1 sec. to several seconds depending on the activity to be examined, at the end of which time the target was automatically brought back to the counting position. As soon as the target reached this position, the counting circuits were automatically closed, the sweep on the Dumont oscilloscope started, and the pulse-height distribution applied to the Tektronix oscilloscope. Photographs could then be taken of either the decay or the pulse-height distribution.

Measurement of Half-life

The output of the counting-rate meter was displayed on the Dumont 241 oscilloscope, for which an external time-base unit supplied a time base of up to 30 sec. in length. Time-marker pulses were applied to the brilliance control at the rates of 2, 20, or 200 per second, and the brilliance turned down so that only bright spots were seen in the photograph. A base line was put in before the target was bombarded. The photographs obtained in this way were enlarged to a standard size and the distance of the spots measured from the base line. The counting rate was then determined from a calibration of deflection versus counting rate obtained previously. At the same time as the photograph was taken, several integral counts above a set bias level were obtained, the first count timed to obtain all of the activity examined, and one or more counts at later times to supply a background subtraction, B.

Corrections were also applied for the counting loss due to the finite resolving time of the apparatus. If the observed counting rate is N_o, then the true rate is given by the expression:

$$N_t = N_o + TN_o$$

The resolving time, T, of this apparatus is 2.3 μsec. The final result, $N_t = N_o + TN_o - B$, was plotted on semilogarithmic paper and the half-life averaged over 3 or 4 half-lives.

Measurements of Energy

With the apparatus described, two methods were employed for the measurement of gamma-ray energies:

(i) A single-channel analyser was available with which the pulse-height spectrum from the NaI scintillation spectrometer was examined. This spectrum was then compared with a calibration curve drawn up from several known gamma-ray sources. The studies on Co^{56} were carried out with this instrument using sources of Cs^{137}, ThC", and Po-Be as calibration points. In most cases the calibration of the instrument was carried out both before and after the examination of the Co^{56} spectrum, so that any drifts in the instrument could be eliminated. Changes in amplifier gain were particularly noticeable within the first few hours after the apparatus was turned on, so that no measurements were made during this time.

(ii) The pulses from the high level output of the main amplifier were squared in the pulse shaper, amplified, and applied to the Y-plates of the Tektronix oscilloscope. The sweep time was adjusted so that the flat top of the pulses covered nearly the whole face of the cathode ray tube. This display of the pulse-height spectrum was photographed for a length of time required to give thirty to forty thousand pulses on one picture,

starting the exposure at the instant the target arrived in the counting position. Sometimes, when the activity was weak, several exposures on one frame were required to build up the necessary density on the film. In such cases the target would be moved ahead, irradiated, and brought back into the counting position without moving the film in the camera.

The photograph was analysed by making an enlargement of the negative and measuring the distance from the base line to the centre of each gamma-ray line. The energies were then obtained from a calibration curve which had been drawn from similar photographs of the pulse-height spectrum of Cs^{137}, ThC", or other convenient source. This method is superior to the original Hofstadter method since the flat topped pulses make it possible to determine the centre of a peak and to measure the distance to the base line more easily and with greater accuracy. Another advantage of this method is that the printing time can be adjusted for differing densities in the negative so that gamma rays differing greatly in intensities can be obtained from the same photograph. Figure 2 illustrates the accuracy of calibration that can be attained by this method.

In order to correlate the observed lifetime with the observed gamma-ray spectrum, several 1 or 2 second exposures were made in a sequence, advancing the film rapidly without closing the shutter. In this way the gamma-ray could be observed to decay in intensity.

Measurement of the Internal Conversion Coefficient

In the process of decaying from an excited state, a nucleus may lose energy by direct emission of a gamma ray, or, if the lifetime of the state is sufficiently long, there is a finite probability of the orbital electrons coming close enough to the nucleus to pick up energy

directly. In this case the entire energy of the transition is transferred to an orbital electron which is then ejected with the energy of the gamma ray less the binding energy of the electron. The total internal-conversion coefficient is defined as the ratio of the number of conversion electrons to the number of gamma rays emitted, i.e.

$$\alpha_t = \frac{N_e}{N_\gamma} \qquad \text{.....(1)}$$

where N_e is the number of conversion electrons emitted per unit time and N_γ is the number of gamma rays emitted per unit time. However, accurate theoretical values are available only for the K-conversion coefficient which is the ratio of the number of K electrons emitted to the number of gammas emitted. In the method to be described here the total-conversion coefficient was measured and to compare with the theory, α_K was obtained by making use of empirical relations giving the ratio of K to L conversion electrons. The conversion in the M, N and higher shells has been neglected.

$$\alpha_K = \frac{N_K}{N_\gamma} = \frac{N_e}{N_\gamma}\,\frac{N_K}{N_e}$$

$$= \alpha_t \,\frac{N_K}{N_K + N_L + \ldots}$$

$$\alpha_K = \frac{\alpha_t}{1 + N_L/N_K} \qquad \text{.....(2)}$$

However, the <u>observed</u> numbers of conversion electrons and gamma rays, $N_e^{\,1}$ and $N_\gamma^{\,1}$, do not give a true picture of the numbers actually emitted. These observed numbers must be corrected for (a) the different solid angles of the two counters, (b) the different

efficiencies for capture of betas and gammas by the two crystals, (c) geometrical efficiencies such as edge effects of the crystals, (d) absorbing materials in front of the crystals, and self absorption of the source, (e) back scattering from the source holder in the case of the electrons, (f) scattering of γ's into the crystals from surrounding materials, and (g) incorrect counting of the β's or γ's because of a continuous distribution on which the gamma-ray peak, or conversion-electron peak, is superimposed. The following equation summarizes the preceding statements.

$$\alpha_t = \frac{N_e'}{N_\gamma'} \cdot \frac{\omega_\gamma}{\omega_e} \cdot \frac{\varepsilon_\gamma}{\varepsilon_e} \cdot \frac{f_e}{f_\gamma} \cdot \frac{a \cdot s}{b} \cdot \xi_\gamma \quad \ldots(3)$$

where ω_γ and ω_e are the solid angles subtended by the crystals of the γ and β counters respectively, ε_γ and ε_e are geometrical efficiency factors, f_e and f_γ are correction factors arising from over-counting of pulses in the peak due to a continuous distribution of pulses such as would arise from Compton scattering of gamma rays, or from decay beta particles. a, s, and b, are factors which correct for the absorption of gammas by intervening material, the scattering of gammas into the gamma counter, and back scattering effects of the source backing material. ξ_γ is the efficiency of the NaI crystal for the production of photo-electrons by gammas. The efficiency of the β counter is considered to be 100%.

The solid angles for the two crystals can be measured fairly easily, as can the efficiency of the crystals for the capture of their respective rays. The back-scattering corrections can be estimated and the absorption of the gammas by intervening material can be obtained, but the values of the other factors are rather more difficult to ascertain. The number of gammas counted by the β counter can be deter-

mined by the use of absorbers to remove the conversion electrons, but if the interference is from other betas, then these also will be absorbed and errors will be introduced.

In view of these facts, it was thought advisable to measure the conversion coefficient by comparison with a source whose conversion coefficient is known. This source should have a gamma ray of similar energy and one which will give a clear conversion-electron spectrum with little or no interference from decay betas or Compton electrons.

For these reasons and because of its availability, Cs^{137} was chosen. Although its energy is higher than was desired, it was thought that the unknown correction factors would not vary greatly in this range of energies. Cs^{137} has a single gamma ray associated with the decay of a single β particle and fairly good separation of the conversion electrons from the beta distribution is possible, since the conversion-electron energy is 625 kev and the beta end point is 520 kev. Another beta of 1.18 Mev is present in amounts less than 5% of the total, and so should not cause an appreciable error. The total-conversion coefficient of Cs^{137} has been measured as 0.12[9].

It is evident that the formula for the total-conversion coefficient can be put into the following form:

$$\frac{\pi\alpha_t}{cs\alpha_t} = \left(\frac{\pi N_e'}{\pi N_\gamma'} \cdot \frac{cs N_\gamma'}{cs N_e'}\right)\left(\frac{\pi\omega_\gamma}{\pi\omega_e} \cdot \frac{cs\omega_e}{cs\omega_\gamma}\right)\left(\frac{\pi\varepsilon_\gamma}{\pi\varepsilon_e} \cdot \frac{cs\varepsilon_e}{cs\varepsilon_\gamma}\right)\left(\frac{\pi f_e}{\pi f_\gamma} \cdot \frac{cs f_\gamma}{cs f_\gamma}\right)\left(\frac{\pi a}{cs a}\right)\left(\frac{\pi S}{cs S}\right)\left(\frac{cs b}{\pi b}\right)\left(\frac{\pi f_\gamma}{\alpha f_\gamma}\right) \quad (4)$$

A B C D E F G H

If the sources are in identical positions, then term B will be equal to unity. Terms C, E, F, and G can also be neglected because the conditions of the two sources have been made as nearly identical as

possible. Not much can be said about term D which contains corrections to be applied because of poor resolution or because of background betas or gammas, and so neglect of this term probably contributes the major part of the error experienced. However, the following approximate expression should give the conversion coefficient to within 30% providing α_t^{Cs} is known accurately.

$$\frac{\alpha_t^{Tl}}{\alpha_t^{Cs}} \doteq \left(\frac{N_e'}{N_\gamma'}\right)^{Tl} \cdot \left(\frac{N_\gamma'}{N_e'}\right)^{Cs} \cdot \frac{\xi_\gamma^{Tl}}{\xi_\gamma^{Cs}} \quad \ldots\ldots(5)$$

The following method was used to measure the number of pulses in the photoelectron peak and the number of electrons in the conversion-electron peak of the beta counter.

First, by means of artificial pulses, the oscilloscope deflection was measured, and plotted against the pulse height at the output of the amplifiers as indicated by the discriminators. Such a curve was obtained for both amplifiers and for all settings of the attenuator on the pulse-clipper unit. The beta and gamma counters were mounted in the counter holder of the target-extraction unit (T.E.U.) on opposite sides of the source position. The source was mounted in the jaws of the target holder of the T.E.U. and its position adjusted so that when the compressed air was applied, the source was in line with the counters. The Cs^{137} source was first placed between the counters and the pulse-height distribution was observed on the Tektronix oscilloscope for both counters. From the curves of scope deflection versus discriminator setting, the position of the valley between the photo-electron peak and the Compton distribution of the gamma counter, and the valley below the electron peak from the beta counter was

determined in terms of discriminator setting. The discriminators were then set at these values and the counting circuits put into operation. Counts were obtained simultaneously from the two counters for a period long enough to give several thousand pulses.

The thin target of HgO was then mounted in the target holder in as nearly the same position as possible as the Cs source. This was bombarded in the cyclotron for about 1 second at the end of which time it was brought back into the counting position by applying compressed air to the pneumatic cylinder of the probe. Preliminary bombardments were made to determine the position of the peaks and the valley below the peaks. The discriminators were set on these valleys as before and then several irradiations were performed in order to increase the count.

Several runs were also made with an absorber over the beta counter to eliminate all electrons from this counter. All counts obtained in this manner were therefore due to gamma rays producing Compton recoil electrons in the stilbene crystal. The results were normalized with the gamma counter and these were then subtracted from the counts obtained without the absorber. The γ-ray background in the β counter was obtained for the Cs source also. The total-conversion coefficient $\alpha_t^{\pi\ell}$ was calculated using formula (5).

From the value of the total internal-conversion coefficient measured in this way, the K-conversion coefficient was calculated from the empirical values of the K to L ratios summarized in the article by Goldhaber and Sunyar for magnetic and electric transitions[10]. The value of α_K was then compared with the theoretical values given in the tables and graphs of Rose, et al.[11] to determine the multipole order of the radiation.

EXPERIMENTAL RESULTS

Calibration

It has been shown[3] that the light output of a NaI crystal is proportional to the energy of the gamma ray absorbed by that crystal. It is therefore essential that all electronic units necessary for the measurement of the gamma-ray energy be linear with respect to pulse height, so that the output is also proportional to the gamma-ray energy. Otherwise, calibration of the instrument becomes difficult, and the results uncertain. All units used in the scintillation spectrometer described here were checked for linearity of operation separately, and as an entire unit. In the measurements on the individual units, artificial pulses were fed into the units, and the input and output pulses measured by means of the calibration control on the Tektronix 513D oscilloscope. In this way all units were found to be linear within the limits of the measurement, except that the pulse shaper was non-linear for small pulse sizes of 0 - 2 volts amplitude. The only limitation this entails is that the pulse output from the Al amplifier must always be kept well above this level.

More significant perhaps is the overall linearity of the equipment. This was tested by obtaining a pulse-height spectrum for sources of Cs^{137}, Co^{60}, and ThC", with the channel analyser, and plotting the energy against the pulse height at the peak. Figure 3 shows the pulse-height spectrum of each of the above calibration sources, and on the same figure is plotted the calibration curve of energy versus pulse height. The figure illustrates clearly the linearity of the scintillation spectrometer and the pulse-height analyser.

The linearity of the system using the modified Hofstadter technique of photographing the pulse-height spectrum is illustrated in

Figure 2. It can be seen that the accuracy in locating the centre of the peaks is good.

Resolution of the Counter

The resolution of the spectrometer is defined as the full width of the peak at half maximum divided by the pulse height at the peak. This varies roughly inversely as the square root of the energy of the gamma ray. To see how the resolution of the counter used in this experiment varied with energy, the background was drawn in as nearly as possible and subtracted from the peak. In this way the resolution was measured for gamma-ray energies from 78 kev to 3.4 Mev. The resolution was about 36% at 78 kev decreasing to 6% at 3.4 Mev with a value of 11% at 0.661 Mev. Figure 4 indicates how closely the resolution follows the $E^{-1/2}$ relation. The resolution of the stilbene beta counter was 15% when it was first put into operation but this deteriorated with time.

Energy of the Po-Be Gamma Ray

In the literature are reports of several determinations of the energy of the gamma ray from the Po-Be source[12,13]. Because of the discrepancies in these values, it seemed desirable to check this before using it as a calibration point. This was accomplished by using the lower energy well-known gamma rays of Cs^{137} and ThC^{11} and then extrapolating the calibration curve to higher energies. In this way the energy of the pair peak was found to be 3.41 $\pm$ 0.02 Mev which gives a γ-ray energy of 4.43 $\pm$ 0.02 Mev. It is interesting that Thomas and Lauritsen[14] have recently reported the value 4.432 $\pm$ 0.010 Mev agreeing very closely with the value obtained here.

Gamma Rays from Co^{56}

A strip of spectrographically pure iron was irradiated in the cyclotron for about 7 hours with 15 Mev protons. The only interfering activities that would be produced are 270 day Co^{57} and 72 day Co^{58}. These would be produced by reactions on Fe^{57} and Fe^{58} which are present in only small abundance, so very little activity would be expected from them. The source was allowed to decay for several weeks prior to the measurements to allow for the disappearance of 18 hour Co^{55} and other short-lived activities. No chemical separation was performed.

A plot of the pulse-height spectrum of Co^{56} is given in Figure 5 along with the calibration points mentioned previously. The calibration curves were obtained both before and after the spectrum of Co^{56} was taken and no drift in the apparatus was noted. The average values obtained for the energies of Co^{56} gamma rays are listed in Table 1, together with the values measured by Elliott and Deutsch[15]. Also given are the relative intensities.

TABLE 1

Designation	Relative Intensity	Energies (Mev) Experimental	Elliott and Deutsch
γ_1	1	0.85 ± 0.02	0.845
γ_2	0.55	1.26 ± 0.02	1.26
γ_3	0.22	1.82 ± 0.04	1.74
γ_4	0.06	2.12 ± 0.04	2.01
γ_5	0.12	2.65 ± 0.04	2.55
γ_6	0.08	3.27 ± 0.02	3.25

In order to provide some further information which might aid in the construction of a decay scheme, it seemed desirable to measure the

relative intensities of the gammas. This has been accomplished by subtracting the background radiation from the photoelectron peaks, measuring the area of the peaks with a planimeter, and correcting these areas for the efficiency of the NaI crystal for photoelectron production at the various energies. The efficiency of the crystal was calculated as follows.

The total absorption coefficient, μ, is defined by the equation:

$$\frac{I}{I_0} = e^{-\mu x} \qquad \text{.....(6)}$$

where $\mu = \sigma + \tau + K$ and I_0 is the intensity incident on the crystal. σ is the cross section for Compton scattering, τ is the cross section for photoelectron production, and K is the cross section for pair production. If μ is measured in cm^2/atom, then x is in atoms/cm^2. Since these three processes are completely independent, they may be calculated separately from one another. Therefore for the photoelectron process, $\frac{I}{I_0} = e^{-\tau x}$.

NaI is 85% by weight iodine and 15% by weight sodium, and since the absorption coefficient varies as Z^5, the sodium plays only a very small part in the process and thus can be neglected in the calculations. Number of atoms of iodine per $cm^2 = x = \frac{\rho\ t\ N}{A}$ .....(7)

where ρ (density) = 3.67 gms/cm.

t (thickness) = 2.54 cm.

N (Avogadro's no.) = 6.023×10^{23}

A (mass number) = 150

Therefore for the 1 inch crystal, $x = 3.75 \times 10^{22}$ atoms/cm^2.

τ was obtained from the graphs of Davisson and Evans[16] in which values of $\frac{\tau}{Z^5 n}$ are plotted against Z for various values of

n. ($n = mc^2/h\nu$). Table 2 summarizes the steps in the calculation of the efficiency of the NaI crystal for photoelectron production. The efficiency equals $\frac{I_o - I}{I_o} = 1 - e^{-\tau x}$.

TABLE 2

Energy	Area of peak	$n = \frac{0.51}{E}$	$\frac{\tau}{Z^5 n}$	τ	$e^{-\tau x}$	Efficiency
0.85	428	0.68	0.53×10^{-32}	1.51×10^{-24}	0.9450	0.055
1.26	105	0.42	0.38×10^{-32}	0.66×10^{-24}	0.9754	0.0246
1.82	22.8	0.28	0.31×10^{-32}	0.36×10^{-24}	0.9865	0.0135
2.12	4.6	0.24	0.28×10^{-32}	0.28×10^{-24}	0.9894	0.0106
2.65	7.5	0.19	0.27×10^{-32}	0.22×10^{-24}	0.9918	0.0082
3.27	3.6	0.16	0.25×10^{-32}	0.16×10^{-24}	0.9939	0.0061

When the areas of the peaks in the Co^{56} spectrum are corrected for the efficiency of the crystal as calculated above, the relative intensities of the transitionsbecome :

$$\gamma_1/\gamma_2/\gamma_3/\gamma_4/\gamma_5/\gamma_6 = 1/0.55/0.22/0.06/0.12/0.08.$$

Isomeric transition in Thallium

A mercury target bombarded in the cyclotron at 33 Mev indicated the presence of a new activity of about 1/2 sec. half-life and 384 kev energy. This same activity was produced when thallium was bombarded at 80 Mev. Targets of platinum and gold were also bombarded at low and high energies but this particular activity was not produced from them. These results indicate that an isotope of thallium is probably the source of this activity.

The mercury targets used in the half-life and energy determinations consisted of a cylinder about 1 - 2 mm. in diameter and 1.5 cm. long, made from cobalt foil 0.0014" thick. This was filled with "spec-pure" mercury and the ends pinched shut. The Hg target used to observe the conversion-electron spectrum was made by dusting HgO on the end of a strip of Co foil on which a thin coating of zapon lacquer had been brushed. Care was taken to prevent any of the HgO from remaining on the reverse side of the Co holder. The thallium target was a small rivet of Tl that had been hammered into a hole in the end of a Co strip 1/4 inch wide and 1 inch long. A similar piece of cobalt was welded at right angles to the first strip to prevent scattered protons from striking the aluminum target holder.

The mean value of the half-life from 10 runs listed in Table 3 is 0.54 $\pm$ 0.01 seconds, the uncertainty being the standard deviation of the ten runs from the mean.

TABLE 3

Run no.	Bombarding energy (Mev)	Bombardment time (sec.)	Initial Counting rate counts/sec	Background counts/ sec.	half-life sec.
Hg - 2 - 19	33.5	0.1	28,000	1080	0.528
Hg - 2 - 20	33.5	0.1	27,000	1180	0.543
Hg - 2 - 21	33.5	0.1	29,000	1230	0.532
Hg - 4 - 2	27.5	0.1	17,000	850	0.544
Hg - 4 - 3	27.5	0.1	14,000	910	0.547
Hg - 4 - 5	27.5	0.2	29,000	1200	0.544
Hg - 4 - 6	27.5	0.2	21,000	1260	0.524
Hg - 4 - 7	27.5	0.2	31,000	1360	0.547
Hg - 4 - 8	27.5	0.2	26,000	1430	0.548
Hg - 4 - 10	27.5	0.2	28,000	1760	0.546

A photograph of the oscilloscope display of the counting-rate meter output with time markers is shown in Plate I. Figure 6 is a plot of the activity induced in run Hg - 4 - 6 on semilogarithmic paper with the time markers as abscissae.

A plot showing the relative yields of activity at varying bombardment energies is given in Figure 7. The points in this curve were obtained by averaging over three runs the total activity induced in the target for the entire decay period. Long period background was subtracted. This curve indicates that the threshold for production of this activity from a mercury target is about 13-1/2 Mev. The bombarding energies were obtained from the laboratory chart showing the proton beam energy versus target radius. The cobalt foil surrounding the target subtracts about 1 Mev from the proton beam at this energy so that the threshold when corrected for this becomes about 12-1/2 Mev.

Figure 8 is a semilogarithmic plot against time of the activity produced from the bombardment of thallium at 80 Mev. When the long period background is subtracted, there remain two activities, one of 5.6 sec., and the other of 0.52 sec. half-life. The 5.6 sec. period is identified as the isomeric transition in Pb^{202} investigated by Hopkins in this laboratory[2], while the 0.52 sec. period is the same as that produced in the mercury target.

The thallium target was also subjected to bombardments at increasing energies to determine the threshold for production of this activity. The measurements here are complicated by several factors, (a) the bombardment of thallium produces Pb^{204m} which decays with a gamma of very nearly the same energy as the activity under investigation, and (b) the 5.6 sec. activity of Pb^{202} makes it very difficult to subtract

the proper background to give the total count due to the 0.5 sec. activity. An attempt was made to obtain the threshold by setting the channel analyser on the gamma-ray peak and use the output of this to operate the counting-rate meter. This proved unsuccessful because of the Pb^{204m} activity building up rapidly and masking the shorter lived radiation. The method that was finally used was to draw a crude decay curve at each energy and then subtract long-lived background and a 5.6 sec. background. The remaining count was assumed to be due to the short-lived activity. In this way the yield curve of Figure 9 was obtained. This curve has been corrected for the variation in proton beam current with radius. The threshold determination was stopped at 57 Mev because at energies lower than this the 5.6 sec. activity became so intense as to mask completely the short activity. The shape of the yield curve appears to be due to the occurrence of the two stable isotopes of thallium, Tl^{203} and Tl^{205}. If the lower part of the curve is projected to the axis, a threshold of 45 to 50 Mev results. The upper part of the curve indicates a threshold of 55 to 60 Mev.

Table 4 lists the results of measurements of the gamma-ray energy from six photographs chosen at random. The mean energy obtained from 14 such photos is 384 $\pm$ 6 kev. The uncertainty is the standard deviation of the mean calculated from the uncertainty of measurement of the individual values. Calibration points were obtained from the X-ray lines appearing in the same photographs and from a Cs^{137} photo taken separately.

TABLE 4

Hofstadter photo number	Target	Bombarding energy	γ-ray Energy
95	Hg - 4	27-1/2 Mev	376 ± 15 kev
97	Hg - 4	27-1/2 Mev	381 ± 15 kev
108	Hg - 4	27-1/2 Mev	374 ± 25 kev
242	Tl - 5	80 Mev	388 ± 20 kev
239	Tl - 5	80 Mev	388 ± 25 kev
333	Hg - 4	30 Mev	387 + 25 kev

No annihilation radiation was observed. Plate II illustrates the decay of the 384 kev line in a series of photos taken in succession. The peak that appears at about 220 kev is the Compton peak of the 384 kev gamma ray.

Measurement of the Conversion Coefficient

The thin HgO source (Hg - 6) was irradiated for 1 second, then brought back by the rapid-target-extractor to the counting position between the γ and β counters so that counts from both were obtained simultaneously and for the same length of time. The bias on the discriminators of the two amplifiers was set so that only those pulses in the photo peak of the γ counter and the conversion-electron peak in the β counter would be counted. In the results given the total counts are the sum of three separate runs, each counted for about 2 seconds.

An absorber was then placed in front of the beta counter to absorb all electrons so that only electrons from Compton scattering inside the stilbene crystal would be counted. The above runs were repeated until the γ counter recorded about the same numbers of pulses as before. The number of pulses from the β counter was normalized with

the gamma count and subtracted from the counts taken without the absorber to give the true number of electrons. Plate III is a photograph of the pulse-height spectrum from the beta counter.

With a Cs^{137} source in place of the HgO target, the same procedure was followed. Table 5 summarizes the results of these runs.

TABLE 5

	Number of Counts in the peak			
		beta counter		
Source	gamma counter	no absorber	with absorber	corrected count
Cs^{137}	15,500	13,800	600	13,200
Tl^{197}	1,110	7,640	1,370	6,270

The efficiency of the gamma counter at the energies of 661 kev and 384 kev was calculated by the method described previously with the results $\int_\gamma^{Cs}$ = 8.6% at 661 kev and $\int_\gamma^{Tl}$ = 28% at 384 kev. Therefore, using equation (5) in which α_t^{Cs} is 0.12,

$$\alpha_t^{Tl} = 2.61.$$

Two other determinations were made at different times with different photomultiplier tubes, with different resolution and gain, with the results 2.37 and 3.11 respectively. The mean value of the three measurements is 2.70.

The K/L ratios were obtained for the various possible multipole assignments from the empirical relations given by Goldhaber and Sunyar[10] and from these the K-conversion coefficients were calculated with equation (2). Table 6 lists these results and gives also in column 4 the values of α_K from the graphs of Rose et al. for the same

TABLE 6

Transition	K/L	α_K (experimental)	α_K (theoretical)
E3	1.6	1.67	0.09
E4	0.6	1.01	0.24
M3	4.7	2.22	1.35
M4	1.8	1.74	3.20

type transitions. From these values the transition would appear to be either M3 or M4.

Short Activities Produced from Gold

The gold target used in the measurement of half-life and threshold consisted of a 2 mil thick piece of gold foil doubled over to give some rigidity and welded to a heavier cross piece about 1 inch long by 1/2 inch wide. This cross piece was to prevent scattered protons from hitting the aluminum target holder. The other target, Au - 3, was made by evaporating several layers of gold onto the end of a cobalt foil 0.0014" thick. This thin target was necessary to keep down the activity produced so as not to mask the gamma-ray peak. It was not until this target was used that the gamma ray causing the short period was discovered.

On bombardment at 9-1/4 Mev, no activity was produced. At 13 Mev and 17.2 Mev the activity was 7.4 sec. Au^{197m}. Figure 10 shows the decay of the activity produced in Au - 2 at a bombarding energy of 17.2 Mev. In the same figure is seen the change in activity when the bombarding energy was raised to 50 Mev. A new short activity is now seen at the beginning of the decay. When the energy was raised still further, another activity became evident. This is seen in Au - 2 - 55, Figure 11, where the 7.4 sec. background from Au^{197m} appears to become shorter. In Au - 2 - 26, Figure 11, this new period can just be

resolved from the 7.4 sec. radiation of Au^{197m} and appears to have a half-life of about 1.8 sec. Table 7 summarizes the results of the measurements on the short half-life produced from gold.

TABLE 7

Run no.	Bombarding energy (Mev)	Bombardment time (sec.)	Initial counting rate (counts/sec.)	half-life (sec.)
Au - 2 - 65	50	0.1	570	0.425
Au - 2 - 66	50	0.1	1100	0.332
Au - 2 - 64	50	0.1	2000	0.446
Au - 2 - 62	50	0.1	3500	0.446
Au - 2 - 63	50	0.1	3500	0.306
Au - 2 - 26	80	0.1	10000	0.396
Au - 2 - 29	80	0.1	20000	0.457

The mean value of seven determinations is 0.40 ± 0.06 sec. where the uncertainty is the standard deviation of the individual measurements from the mean. The last two runs taken at 80 Mev also show a longer period of 1.81 and 1.89 sec. half-life. These periods were subtracted to obtain the shorter lifetime.

Plate IV shows a photograph of the pulse-height spectrum of the short-lived radiation obtained from gold. Four gamma-ray lines with energies 273, 134, 77, and 48 kev are clearly visible. The 273 and 77 kev lines are the γ rays from the decay of the isomeric level in Au^{197} and have been used as calibration points in every photograph. The fast disappearance of the other two lines connect them with the 0.40 sec. activity observed with the counting-rate meter. The mean value of the energy of the two γ-ray lines from 15 photos are 134 ± 4 kev and 48 ± 4 kev where the uncertainty is the standard deviation

determined from the uncertainty in the calibration curve. Table 8 summarizes the results of energy measurements from 10 photographs.

TABLE 8

Photo number	Bombarding energy Mev.	Gamma ray energy γ_1	γ_2
511	80	50 ± 10	133 ± 10
512	80	51 ± 10	136 ± 10
497	70	44 ± 10	133 ± 10
498	70	46 ± 10	139 ± 10
505	70	46 ± 10	129 ± 10
508	80	49 ± 10	135 ± 10
510	80	52 ± 10	139 ± 10
493	70	49 ± 10	134 ± 10
494	70	51 ± 10	137 ± 10
501	70	48 ± 10	134 ± 10

Bombardments were carried out on platinum targets to see if this 0.40 sec. activity could be produced. No radiation with this half-life was obtainable with the counting-rate meter and analysis of Hofstadter photos showed no 134 kev and 48 kev lines of short life. Some 130 kev γ-ray activity was observed but this was long-lived and seemed unrelated to that which is produced in the gold target. The mercury photographs were also searched for this activity and some evidence was found. Other mercury photos were taken at higher energy than had heretofore been used with the Hg target. These runs showed definite evidence of a short-lived line appearing at about 140 kev and in two photos also at 48 kev.

These results indicate strongly that an isotope of mercury is responsible for the two gamma rays observed. No annihilation radiation was observed other than what is normally present as a background radiation.

An attempt was made to obtain the threshold for production

of this activity. Again the complex spectrum and decays that appear when gold or mercury is bombarded prevented an accurate measurement of the threshold energy. No determination at all was possible from the mercury target because of the presence of the 0.54 sec. Tl isomer, except that the line appeared in photographs at 40 Mev and perhaps very weakly at 33 Mev. Figure 12 shows the results of bombardments on the Au target at various proton energies. A threshold of 25 ± 5 Mev is indicated.

Short-lived Activity from Platinum

Targets of platinum were bombarded in the cyclotron with proton energies from 13 to 33.5 Mev. At 13 Mev, the decay appeared to be entirely due to the 7.4 sec. Au^{197m}, but as the energy was increased this period appeared to shorten. This indicates the presence of another period shorter than 7 sec. but not short enough to be resolved from it on a short time base. When the length of the time base was increased to 20 sec. or longer, the decay lengthened out in the lower part into a 7 sec. slope. A subtraction was then possible in several photographs to obtain an activity with a half-life of 2.0 ± 0.3 sec. Because of the poor statistics in the lower part of the decay curve, the accuracy of the half-life determination is correspondingly poor. Figure 13 shows the decay of Pt - 3 - 33 which was one of the best decay curves showing clearly both the 7 sec. and the 2 sec. activities.

The mean value of 6 determinations of the half-life, 4 from photographs in which a 7 second subtraction was possible and 2 from photographs of gold irradiated at high energy, is 2.0 ± 0.3 seconds.

As yet no gamma-ray lines have been observed in the photographs of the pulse-height spectrum which can definitely be identified

with this 2 sec. activity. All peaks that have been observed seem to be long-period activities. It is possible that some of these long-period gammas that show up coincide with the energy of the 2 sec. period, but this has not been verified. Not much can be said also about the source of this activity, since threshold determinations are very difficult. This activity was present at 19.5 Mev but not at 13 Mev. Also, when gold was bombarded at energies greater than 50 Mev, there were indications of its presence. It therefore seems probable that the activity arises in an isotope of gold with a mass number between 191 and 193.

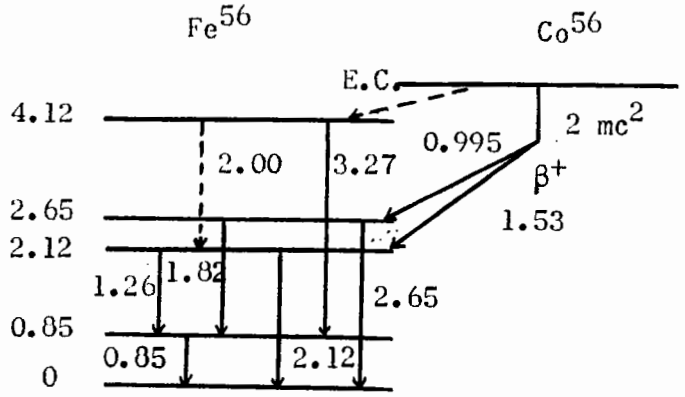
Gamma Rays of Pb^{201} and Pb^{202}

One other result of interest has been noted. Whenever thallium was bombarded, the isomeric states in Pb^{201} and Pb^{202} were excited. The energies of the γ-rays from these isomeric states have been remeasured with the following results. The 5.6 second isomeric level in Pb^{202} decays with a gamma ray of 0.83 ± 0.02 Mev energy as compared with the value 0.89 Mev as measured by Hopkins. The energy of the 50 second transition in Pb^{201} was found to be 0.62 ± 0.02 Mev. Hopkins found gamma rays of this period with energies of 0.67, 0.42 and 0.25 Mev. No sign of the 0.42 or 0.25 Mev γ-rays were found in the pulse-height spectrum obtained here.

DISCUSSION OF THE RESULTS

The energies of the gamma rays resulting from the decay of Co^{56} have been studied, and their relative intensities determined. Cheng et al.[17] have determined the energy of positrons from Co^{56} as 1.53 and 0.995 Mev with relative intensities of 8:3. Elliott and Deutsch[15] report gamma-ray energies from the β^--decay of Mn^{56} as 0.85, 1.81, and 2.13 Mev. Beta-gamma coincidence experiments showed the 0.85 Mev gamma to be in coincidence with the highest energy beta particle, and thus to be the transition from the lowest excited state in Fe^{56} to the ground state. These authors also place the 1.81 Mev gamma ray as a transition from a 2.65 Mev excited state to the 0.85 Mev level, and the 2.13 Mev transition from a 2.98 Mev level to the 0.85 Mev level. In their work on Co^{56}, they have also shown the 1.26 Mev gamma to be in coincidence with the 0.85 Mev gamma ray.

Using the above facts as a guide and the energies measured here, an attempt has been made to construct a decay scheme. The following diagram seems to fit the above facts most closely.



There is some uncertainty in the placing of the 2.12 Mev gamma. It is possible that the 2.98 Mev level is not produced in the decay of Co^{56}, and that it is just coincidence that this level should give a gamma of the same energy as in the decay of Co^{56}.

The position of the 3.27 Mev gamma is only tentative, but the slight indication of a 2.00 Mev gamma in the pulse-height spectrum leads to the assignment given here. Although the measured energies fit into this decay scheme within the accuracy of measurement, further work, especially beta-gamma and gamma-gamma coincidence studies on Co^{56} are necessary to verify this tentative scheme.

Targets of mercury and thallium have been bombarded with protons in the cyclotron producing a new activity with a half-life of 0.54 ± 0.01 sec. and a gamma ray of 384 ± 6 kev. This activity was not produced from gold or platinum, so that the most probable assignment would be to an isotope of thallium. Not excluded, however, would be isotopes of Hg of mass greater than 198. This would require a (p,xnα) reaction on Tl and although such a reaction is not impossible, it seems unlikely to compete with (p,xn) and (p,pxn) reactions. The high threshold for production of the activity from thallium also makes such an assignment unlikely. Since the threshold on Hg is greater than necessary for a (p,n) reaction, it is probable that the Hg isotope of lowest mass is responsible for the threshold determinations. This would be Hg^{196} except for the fact that the abundance of this isotope is only 0.15%, and would therefore hardly enter into the reaction in sufficient amounts. Hg^{198} is the next heavier isotope, with an abundance of 10%, and is therefore considered as the target nucleus in the threshold measurements.

In Table 9, the experimentally observed thresholds are compared with thresholds for several possible reactions, calculated from the table of atomic masses of Metropolis and Reitwiesner[18].

TABLE 9

Target nucleus	Experimental threshold (Mev)	Reactions and calculated thresholds (Mev)		
		p,n	p,2n	p,3n
Hg^{198}	12.5	3.7	10	18
		p,p6n	p,p7n	p,p8n
Tl^{203}	~ 45	42	51	57
Tl^{205}	~ 55	--	--	55

It thus appears that the most probable reactions are $Hg^{198}(p,2n)Tl^{197}$, $Tl^{203}(p,p6n)Tl^{197}$ and $Tl^{205}(p,p8n)Tl^{197}$. Gamma emission following positron decay or K-capture is ruled out by the absence of annihilation radiation, and the fact that observed lifetimes for electron capture in this region are of the order of many minutes or hours. Therefore, the most probable assignment of the 0.54 sec. activity would appear to be an isomeric transition in Tl^{197}.

In order to determine the multipole order of this transition, the experimentally determined lifetimes may be compared with the theoretical value obtained from the relations of Blatt and Weisskopf[19] for the lifetime of a gamma transition of 384 kev. Table 10 lists the theoretical lifetimes and compares them with the experimental values for various multipole orders. The experimental values have been corrected for internal conversion by the formula $\tau_\gamma = \frac{t_{1/2}(1 + \alpha_t)}{\ell n\ 2}$ where α_t has been obtained from the graphs of Rose et al. and the K/L ratios given by Goldhaber and Sunyar.

TABLE 10

Transition	τ_γ (sec.) Theoretical	Experimental
E3	1.4×10^{-4}	0.93
E4	56	1.3
M3	0.025	2.1
M4	9900	5.0

Weisskopf states that these theoretical values may be too small by a factor of up to 1000. This would tend to eliminate the E4 and M4 type transitions as possibilities, leaving either E3 or M3 with a slightly better agreement with the M3 assignment. A comparison of the lifetime and energy with the empirical curves of Goldhaber and Sunyar also leads to an M3 or E3 assignment of the multipole order of the radiation.

The total internal conversion coefficient of Tl^{197} has been measured giving a mean value of 2.7. This leads to an assignment of the radiation as either M3 or M4. The uncertainty is due partly to the approximations made in the development of equation (5), and partly due to uncertainty in the value of α_t^{Cs}, the conversion coefficient of Cs^{137}. The value of α_t^{Cs} used was 0.12 which is the mean of the values given in the charts. J. S. Osoba[20] gives the value $\alpha_K = 0.081$ and K/L = 5.0 which leads to a total conversion coefficient of 0.097, but he reports that this value is probably high. Using this value for α_t^{Cs} gives the value of α_t^{Tl} as 1.8, which agrees more closely with the theoretical value of 1.35 for an M3 transition. In view of the above, it is believed that the 0.54 sec. isomeric transition in Tl^{197} is magnetic 2^4-pole (M3) radiation which entails a spin change of 3 units

and no change in parity.

multipole order $\Lambda = \Delta I + 1$ for magnetic radiation

and $= \Delta I$ for electric radiation

The spins of Tl^{203} and Tl^{205} have been given by Mack[21] as 1/2. It is probable that Tl^{197} with Z = 81 and N = 114 would also have a ground state spin of 1/2 in agreement with the single-particle (shell) model of the nucleus. Thus an M3 transition would lead to a g7/2 assignment of the isomeric level.

A gold target, bombarded with protons at energies above 30 Mev, has been observed to decay with a half-life of 0.40 ± 0.06 sec. and with the emission of two gamma rays of 134 ± 4 kev and 48 ± 4 kev respectively. This activity has been assigned to an isotope of mercury from bombardment of neighbouring elements. Bombardments at various energies indicate a threshold for the production of this activity from gold of about 25 Mev, but little can be said about the threshold from the Hg target other than that it seems to be less than 33 Mev. Table 11 lists several possible reactions with production thresholds calculated from Metropolis' table of atomic masses.

TABLE 11

Experimental Threshold	Reaction	Calculated Threshold
~ 25 Mev	Au^{197} (p,3n) Hg^{195}	15.5 Mev
	Au^{197} (p,4n) Hg^{194}	22 Mev
	Au^{197} (p,5n) Hg^{193}	30 Mev
< 33 Mev	Hg^{198} (p,p3n) Hg^{195}	22 Mev
	Hg^{198} (p,p4n) Hg^{194}	29 Mev
	Hg^{198} (p,p5n) Hg^{193}	37 Mev

Comparison of the experimentally determined with the calculated thresholds suggests that the activity be assigned to Hg^{194}. An assignment to Hg^{195} is not impossible although it seems unlikely that the threshold measurement is as much as 10 Mev in error. An assignment to Hg^{193} is the least probable of the three as the thresholds are definitely less than the calculated value for such an assignment. That an isomeric transition is involved is concluded from the lack of annihilation radiation and the same argument as given before concerning long lifetimes of electron capture transitions in this region.

To obtain the multipole order of the 134 kev gamma ray, comparison was made with the empirical curves of Goldhaber and Sunyar. It was necessary in this case to extrapolate the curves of Rose et al. to lower energy values to obtain the value of α_K used in the calculation of τ_γ, the gamma-ray lifetime. When these values of τ_γ, corrected for internal conversion, are fitted to the graphs in the paper by Goldhaber and Sunyar, agreement is noted only if M3 or E3 corrections are applied. It is not possible at present to decide in favour of one or the other of these possibilities.

A new activity of 2.0 ± 0.3 sec. half-life has been observed from bombardments of platinum and gold. This has been assigned to an isotope of gold with mass number between 191 and 193. No gamma ray has been observed on the pulse-height spectrum photographs but the fact that the activity is present cannot be doubted as can be seen from the decay photographs. It is likely that the energy of the gamma ray if present is the same as that of some of the longer lived radiations present. It may perhaps be about 270 kev in which case the line in the pulse-height

spectrum would be lost due to the presence of the 273 kev radiation from Au^{197m}. Further investigation is required before any definite conclusion may be reached concerning this activity.

The gamma rays from Pb^{201} and Pb^{202} have been remeasured. In the radiations from Pb^{201}, Hopkins found gamma rays of 0.67, 0.42, and 0.25 Mev. It is suggested that the 0.42 Mev peak in the pulse-height spectrum was actually the peak of the Compton distribution, and that the peak that was labeled as the Compton peak of the 0.67 Mev gamma was in reality the photo-peak of a gamma ray of about 0.36 Mev. This could possibly be the gamma ray from Pb^{204m} which has an energy of 0.374 Mev. The 0.25 Mev gamma ray has not been observed in any photograph taken here and is left unexplained. Hopkins' gamma rays of 0.67 Mev and 0.89 Mev have been remeasured as 0.62 Mev and 0.83 Mev respectively.

CONCLUSIONS

A NaI scintillation spectrometer has been used to measure gamma-ray energies, and thereby to investigate new short-lived isomeric transitions in gold, mercury and thallium.

The energy of the gamma ray from a Po-Be source has been redetermined as 4.43 ± 0.02 Mev. The gamma-ray spectrum of Fe^{56} arising from the positron decay of Co^{56} has been investigated. The gamma rays observed have energies 0.85, 1.26, 1.82, 2.12, 2.65 and 3.27 Mev with relative intensities 1, 0.55, 0.22, 0.06, 0.12 and 0.08 respectively.

An isomeric transition of 384 ± 6 kev with a half-life of 0.54 ± 0.01 sec. is assigned to Tl^{197}. The total internal conversion coefficient of 2.7 and lifetime-energy relations lead to an M3 assignment of the multipole order of the radiation.

An isomeric transition of 134 ± 4 kev and 0.40 ± 0.06 sec. has been assigned to Hg^{194}. Another gamma ray of 48 ± 4 kev accompanies the higher energy transition. Lifetime-energy relations label the 134 kev gamma as either M3 or E3.

An activity with a half-life of 2.0 ± 0.3 sec. is produced by proton bombardment of platinum. This is assigned to an isotope of gold of mass 191 - 193.

The gamma-ray energies of Pb^{201m} and Pb^{202m} have been redetermined as 0.62 ± 0.02 and 0.83 ± 0.02 Mev respectively.

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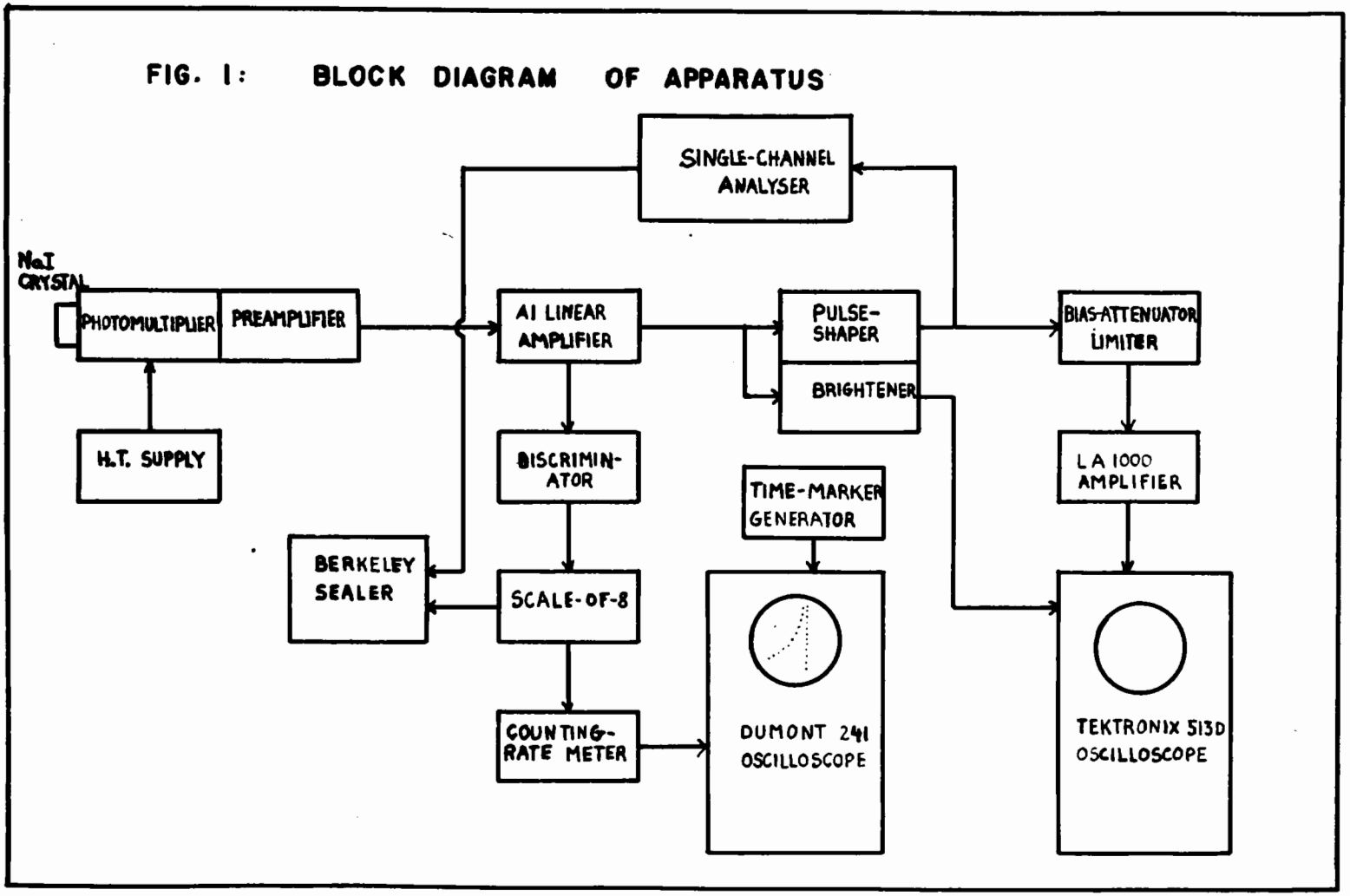
FIG. 1: BLOCK DIAGRAM OF APPARATUS



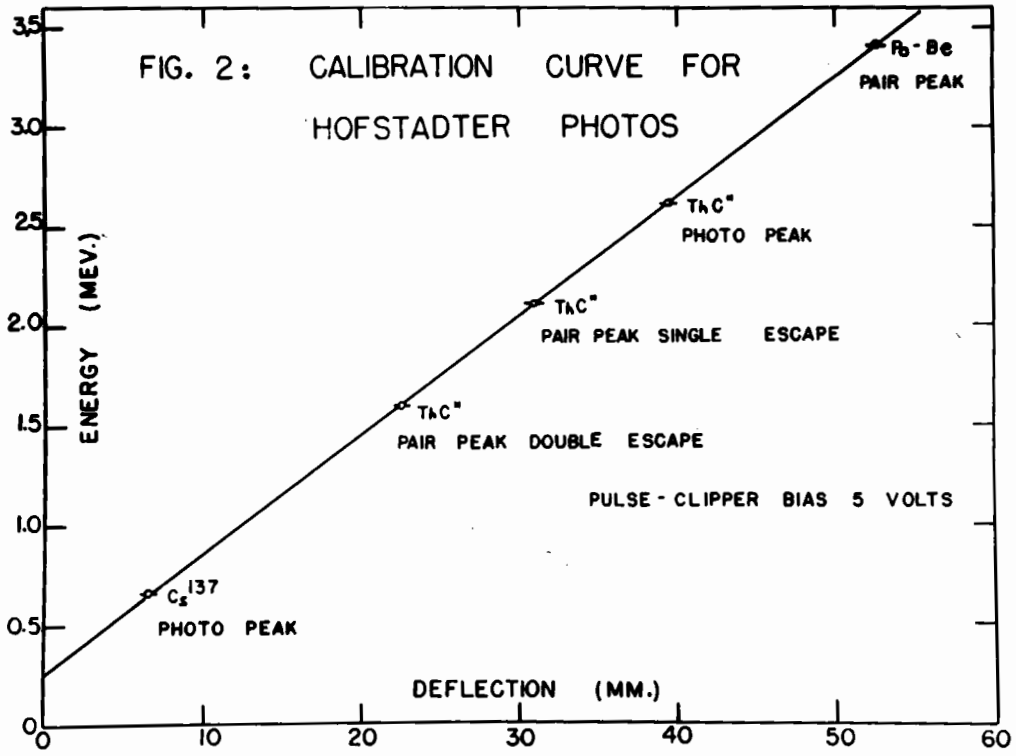


FIG. 2: CALIBRATION CURVE FOR HOFSTADTER PHOTOS
Rb - Be PAIR PEAK
ThC" PHOTO PEAK
ThC" PAIR PEAK SINGLE ESCAPE
ThC" PAIR PEAK DOUBLE ESCAPE
PULSE - CLIPPER BIAS 5 VOLTS
Cs137 PHOTO PEAK
ENERGY (MEV.)
DEFLECTION (MM.)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
10
20
30
40
50
60

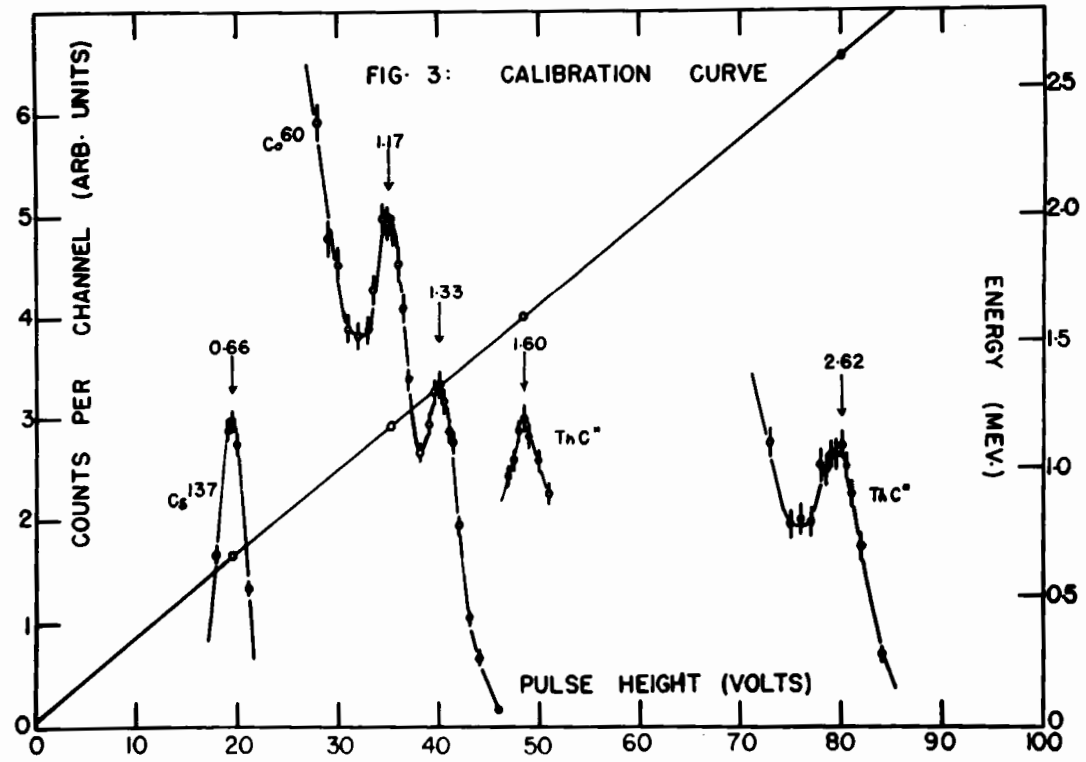


FIG. 3: CALIBRATION CURVE
Co60
1.17
1.33
0.66
Cs137
1.60
ThC"
2.62
ThC"
COUNTS PER CHANNEL (ARB. UNITS)
ENERGY (MEV.)
PULSE HEIGHT (VOLTS)
0
1
2
3
4
5
6
0
0.5
1.0
1.5
2.0
2.5
0
10
20
30
40
50
60
70
80
90
100

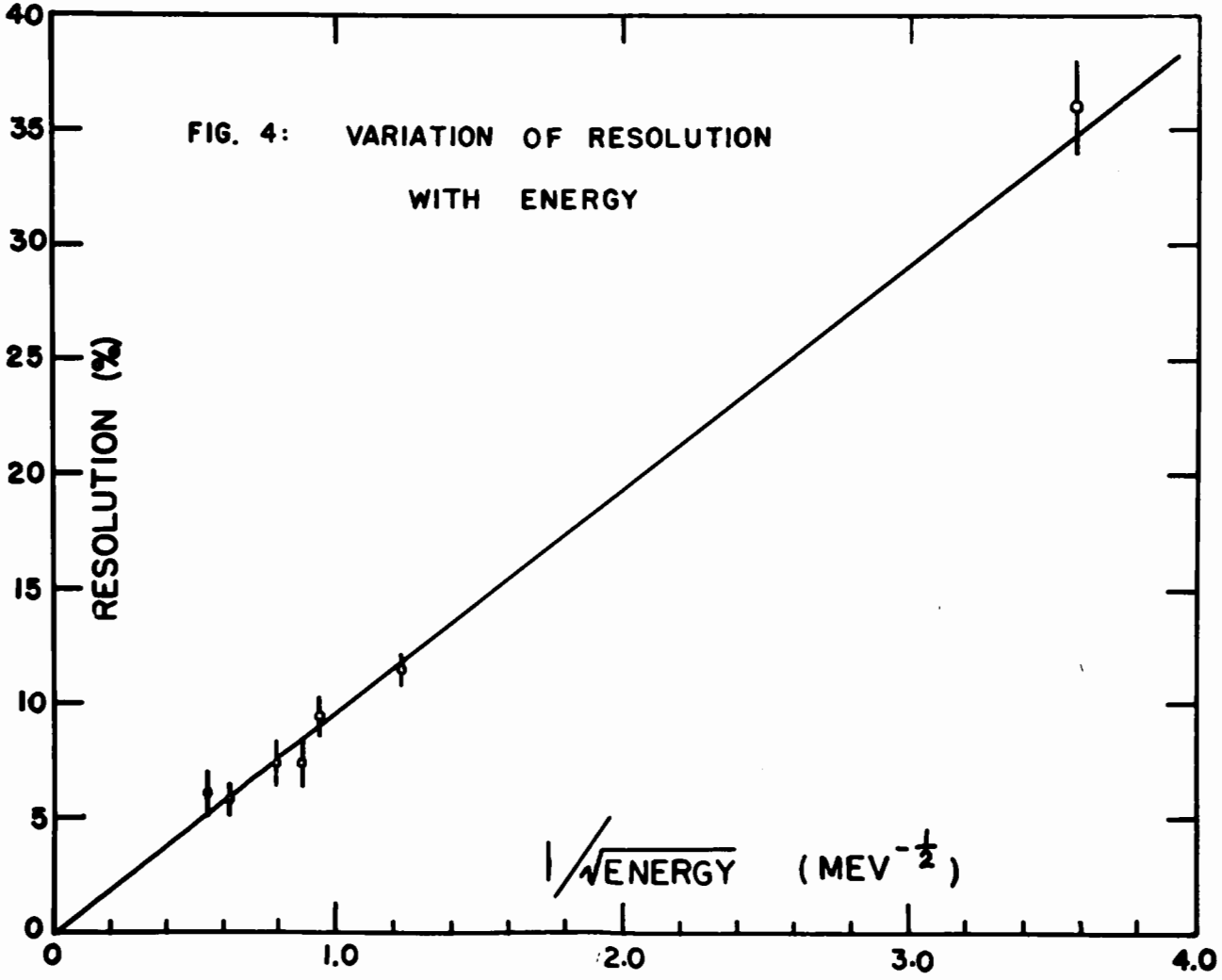


FIG. 4: VARIATION OF RESOLUTION WITH ENERGY
RESOLUTION (%)
40
35
30
25
20
15
10
5
0
0
1.0
2.0
3.0
4.0
1/√ENERGY (MEV^-1/2)

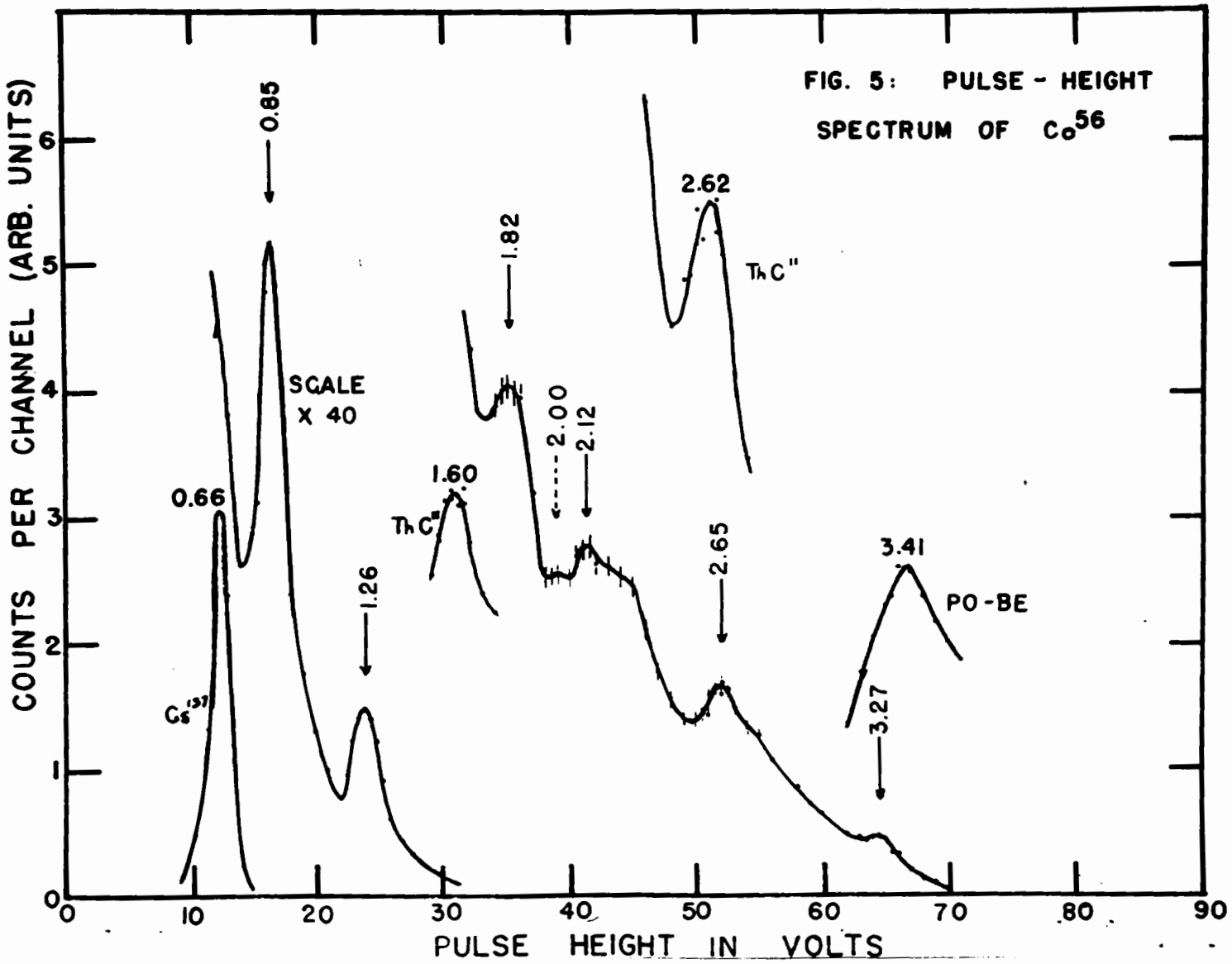


FIG. 5: PULSE - HEIGHT SPECTRUM OF Co^{56}
COUNTS PER CHANNEL (ARB. UNITS)
PULSE HEIGHT IN VOLTS
0.85
SCALE X 40
0.66
Cs^{137}
1.26
1.82
1.60
ThC''
2.00
2.12
2.62
ThC''
2.65
3.41
PO-BE
3.27
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90

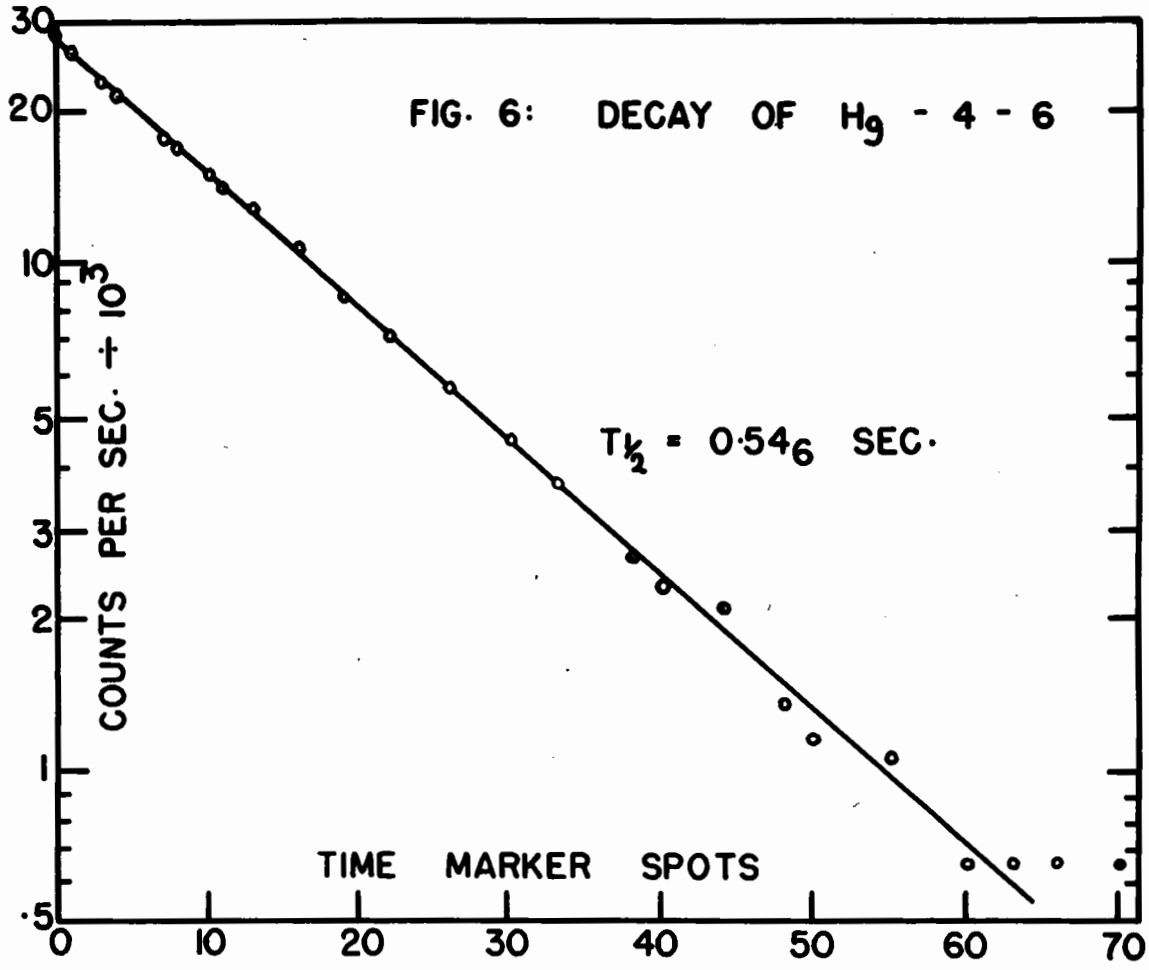


FIG. 6: DECAY OF Hg - 4 - 6

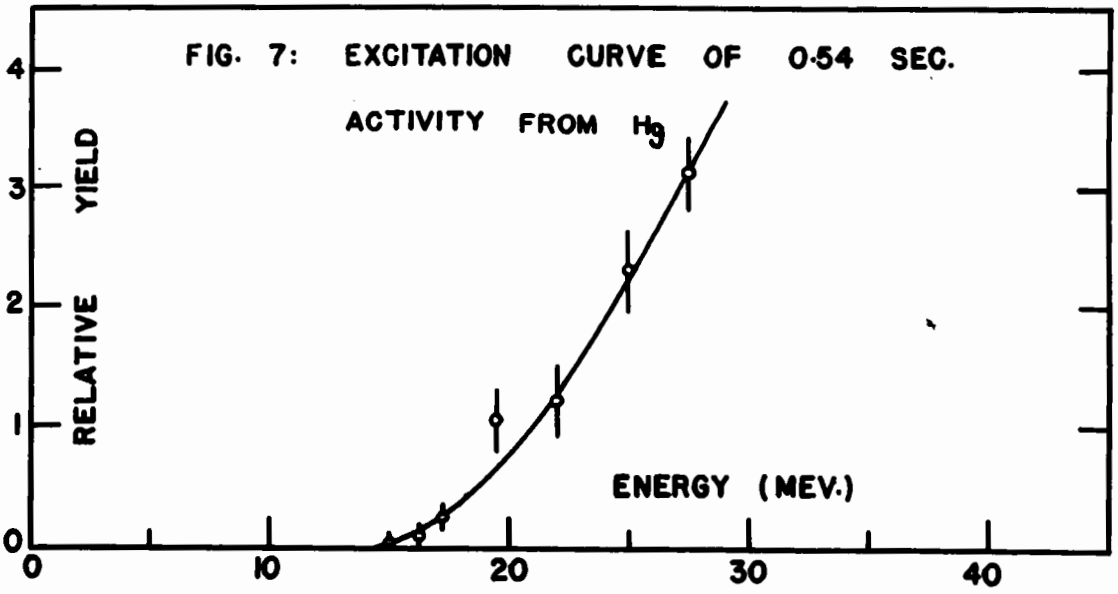


FIG. 7: EXCITATION CURVE OF 0·54 SEC.

FIG. 8: DECAY OF TI - 5 - 14

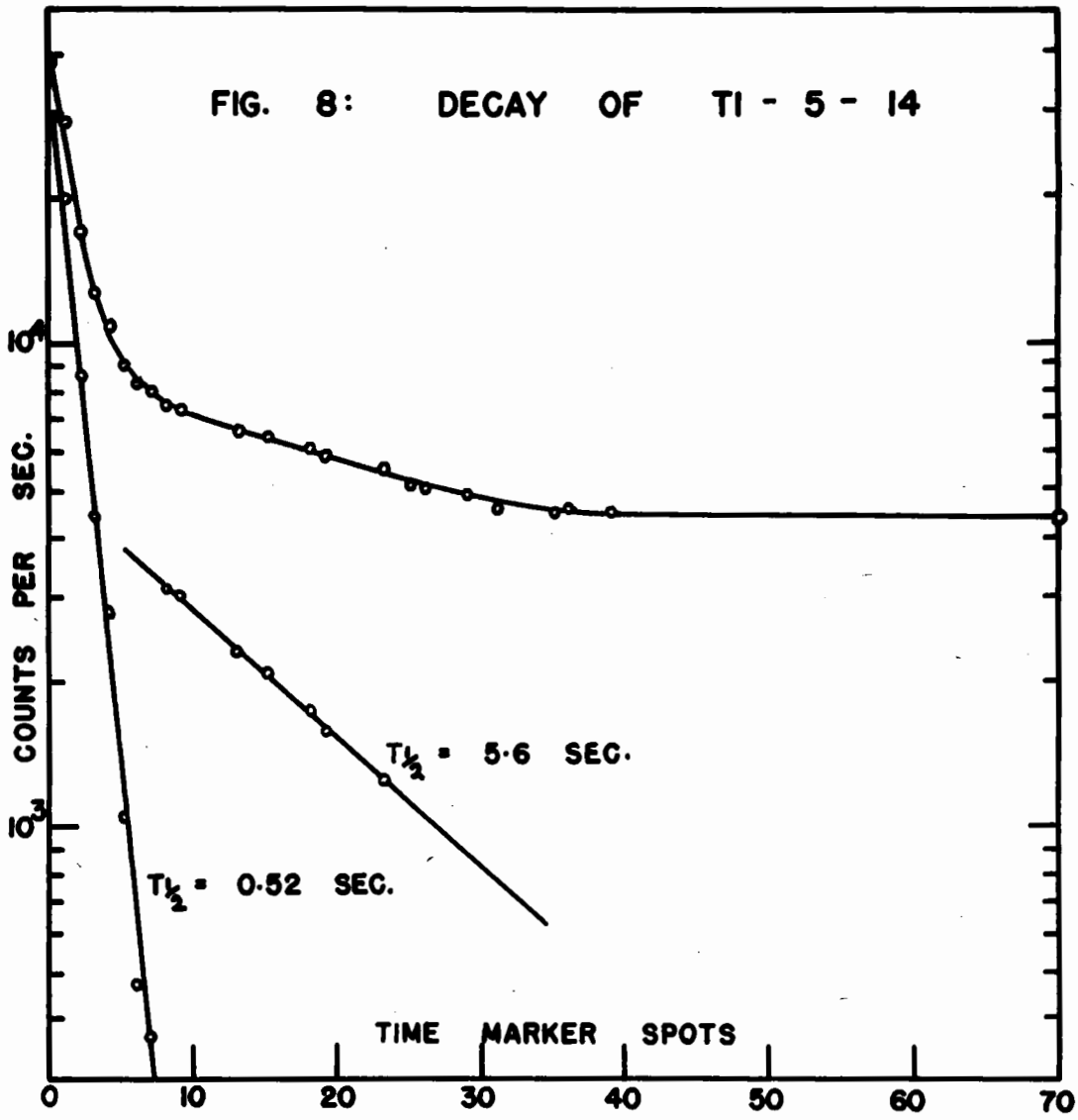
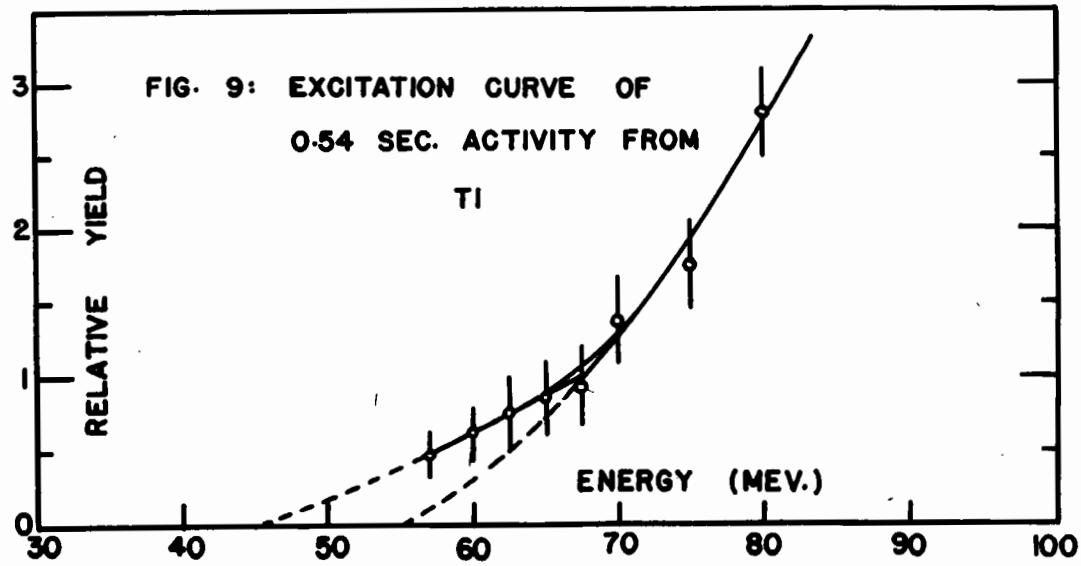


FIG. 9: EXCITATION CURVE OF 0·54 SEC. ACTIVITY FROM TI



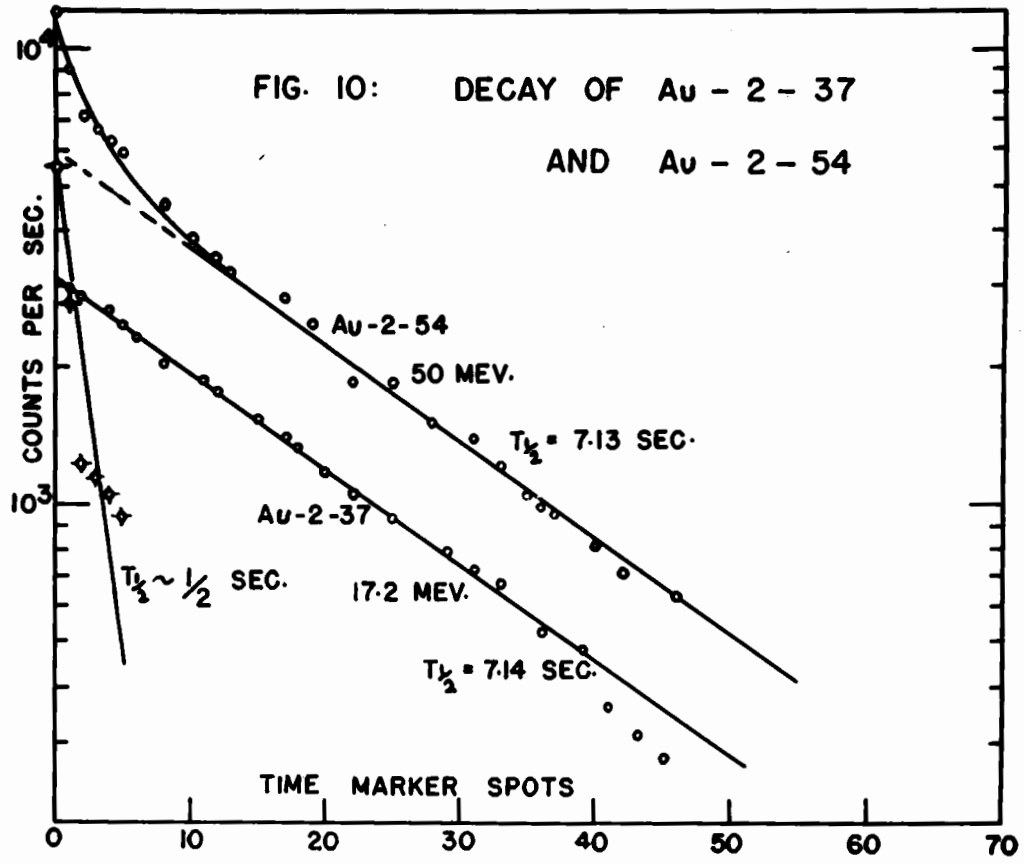


FIG. 10: DECAY OF Au - 2 - 37
AND Au - 2 - 54
COUNTS PER SEC.
Au-2-54
50 MEV.
$T_{1/2}$ = 7.13 SEC.
Au-2-37
17.2 MEV.
$T_{1/2}$ = 7.14 SEC.
$T_{1/2}$ ~ 1/2 SEC.
TIME MARKER SPOTS

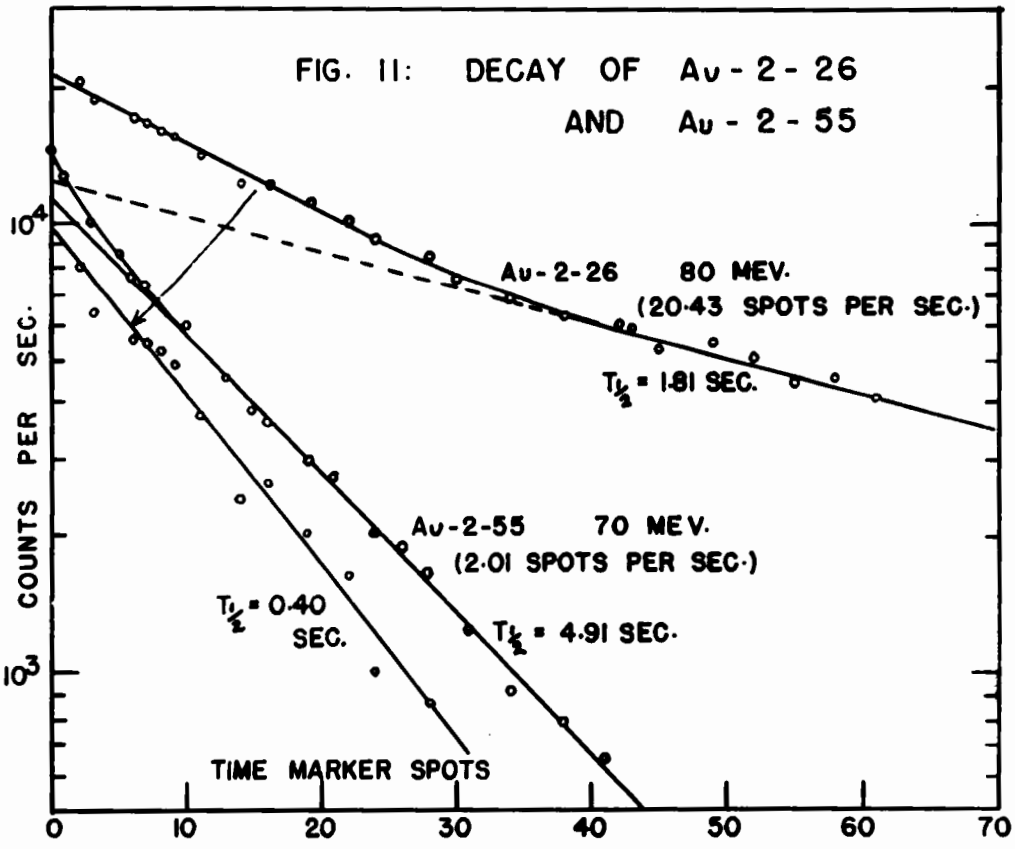


FIG. 11: DECAY OF Au - 2 - 26
AND Au - 2 - 55
COUNTS PER SEC.
Au-2-26 80 MEV.
(20.43 SPOTS PER SEC.)
$T_{1/2}$ = 1.81 SEC.
Au-2-55 70 MEV.
(2.01 SPOTS PER SEC.)
$T_{1/2}$ = 0.40 SEC.
$T_{1/2}$ = 4.91 SEC.
TIME MARKER SPOTS

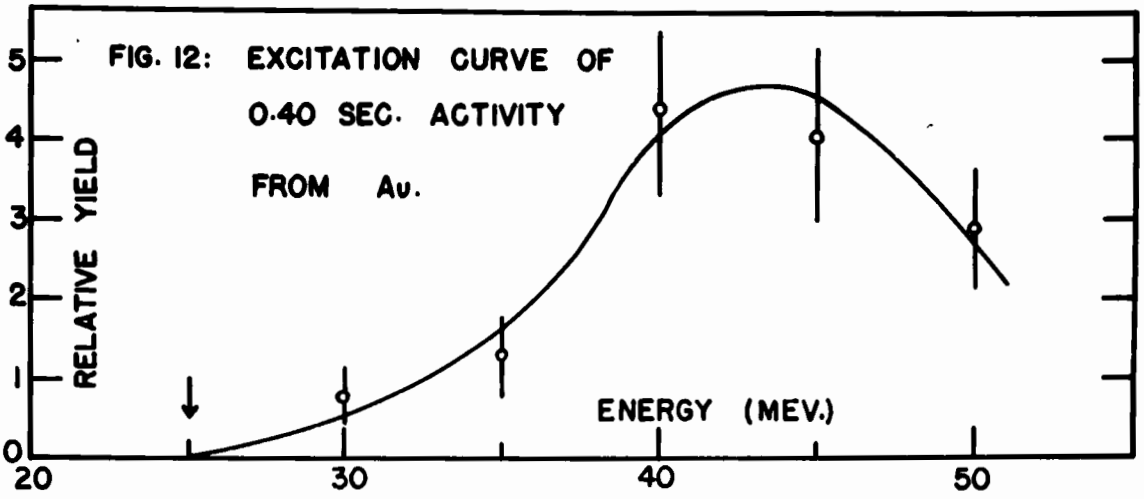


FIG. 12: EXCITATION CURVE OF
0.40 SEC. ACTIVITY
FROM Au.
RELATIVE YIELD
ENERGY (MEV.)
0
1
2
3
4
5
20
30
40
50

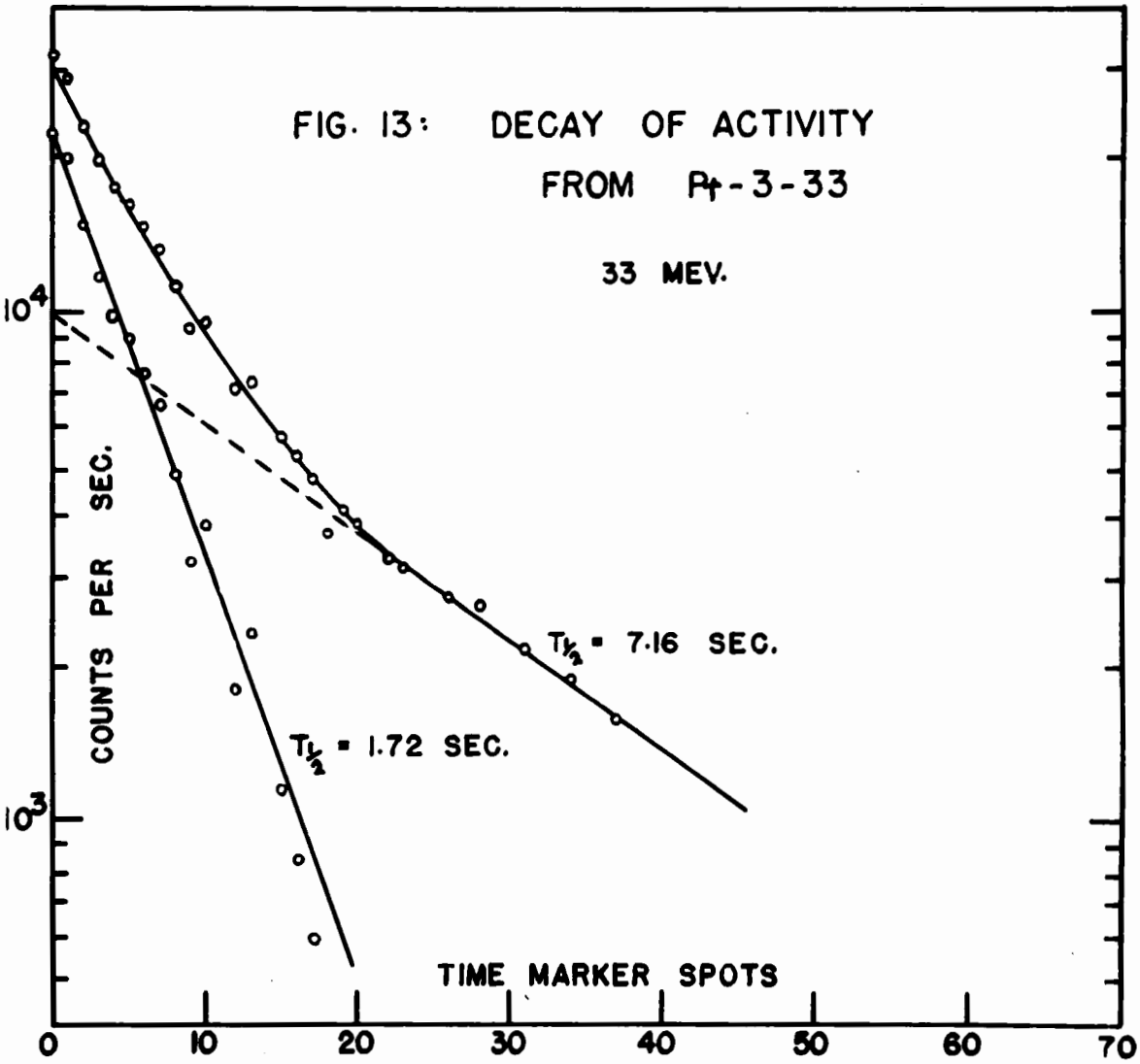


FIG. 13: DECAY OF ACTIVITY
FROM Pt-3-33
33 MEV.
COUNTS PER SEC.
10^4
10^3
$T_{1/2}$ = 7.16 SEC.
$T_{1/2}$ = 1.72 SEC.
TIME MARKER SPOTS
0
10
20
30
40
50
60
70

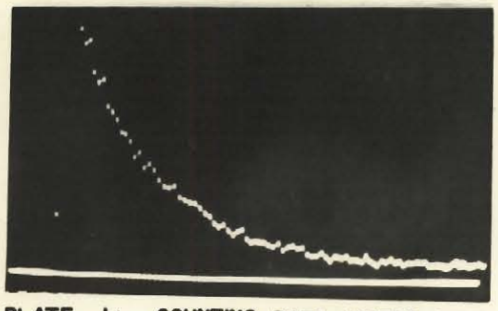


PLATE I: COUNTING-RATE-METER PHOTO OF DECAY OF ACTIVITY IN $Hg - 4 - 10$

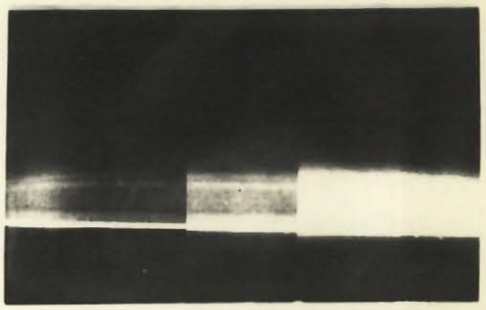


PLATE III: ELECTRON SPECTRUM FROM Tl^{197}

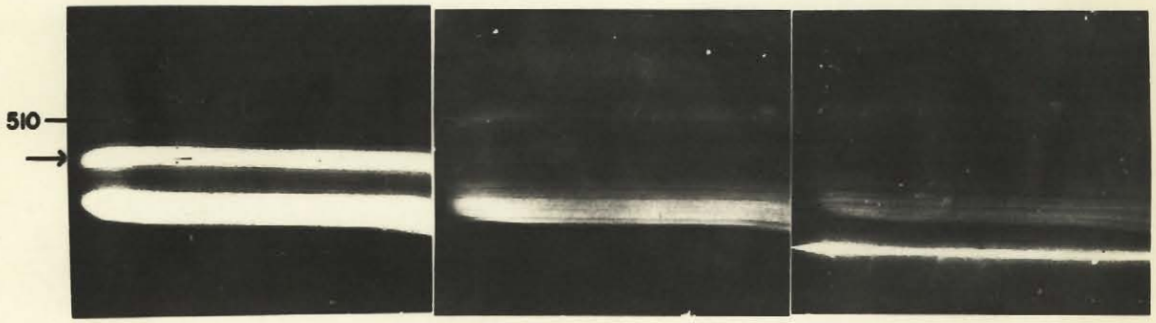


PLATE II: DECAY OF 384 KEV. GAMMA FROM THALLIUM
PHOTOS 2 SECONDS APART

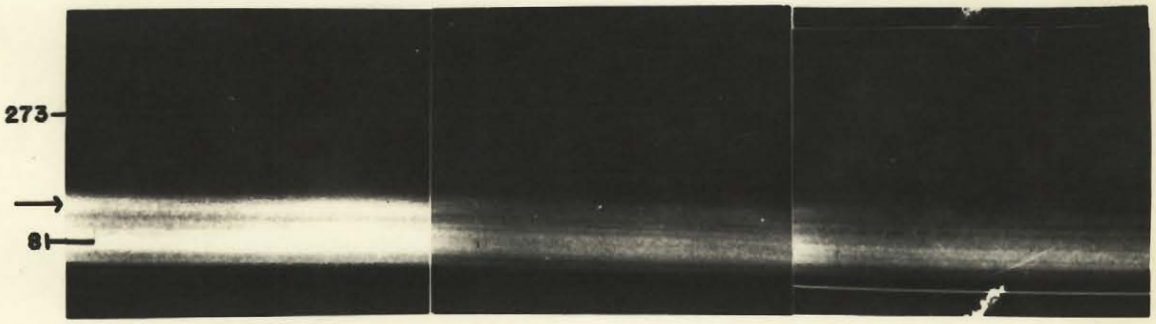


PLATE IV: DECAY OF 134 KEV. GAMMA FROM MERCURY