PRECISION GAMMA RAY ENERGY MEASUREMENTS

PRECISION ENERGY MEASUREMENTS OF THE GAMMA RAYS OF In^{114} USING A LARGE DOUBLE FOCUSING BETA-RAY SPECTROMETER

By

C. DONALD COX, B.Sc.

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TITLE: Precision Energy Measurements of the Gamma Rays of In^{114} Using a Large Double Focusing Beta-Ray Spectrometer

AUTHOR: C. Donald Cox, B.Sc. (University of New Brunswick)

SUPERVISOR: Dr. M. W. Johns

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SCOPE AND CONTENTS:

A double focusing beta ray spectrometer has been constructed and tested in this laboratory. Previous work included investigation of the field shape and tests of focusing, using the Th F line to determine the optimum baffle and counter dimensions.

In this work, a low background coincidence geiger detector has been developed, and a flip coil-galvanometer arrangement has been installed which is capable of giving 0.1% accuracy on magnetic field measurements. Using these improvements, we have investigated the gamma ray spectrum of In^{114}, bringing to light two previously unreported gamma rays, and thus defining a new excited level in Cd^{114}. With a beta source of high specific activity, a search was made for the internal conversion lines due to these gamma rays. An accurate measurement of the beta end point has been obtained.

INDEX

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I would also like to acknowledge the valuable assistance of Dr. R. H. Tomlinson in the preparation of beta sources, and the co-operation and advice of Dr. R. P. Graham who permitted me to use his analytical laboratories. Thanks are due to Mr. T. H. Bryden, our instrument maker, for his valuable advice and ready assistance.

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1. INTRODUCTION

Two of the most important characteristics of a beta ray spectrometer are its resolution, R, the ratio of smallest observable electron momentum change to the momentum, and its transmission, Ω, the fraction of the source-emitted electrons focused. In any instrument, a gain in one of these is achieved only by a loss in the other. It is desirable to have the ratio R/Ω of the spectrometer as small as possible.

By providing an inhomogeneous field shaped to give two-directional focusing, the transmission of the simple semi-circular type spectrometer may be greatly increased without loss of resolution. Svartholm and Siegbahn (1) have shown that an electron leaving the point $(a,0,0)$ in cylindrical co-ordinates, at a small angle to the circle $r = a$ will be focused at $(a,\sqrt{2}\pi,0)$, provided the field in the $z = 0$ plane varies $1/\sqrt{r}$.

Shull and Dennison (2) have shown that this field may be expressed as $H = H_0\left[1 - \alpha\frac{r-a}{a} + \beta\left(\frac{r-a}{a}\right)^2 - \left(\frac{2\beta-\alpha}{2}\right)\frac{z^2}{a^2}\right]$ the two-directional focusing conditions being $\alpha = 1/2$, $\beta = 3/8$

A double focusing instrument has been constructed with $a = 50$ cm. and the field shape examined (3). The parameter β has proven to be closer to 6/8 than 3/8, but the performance is such that further machining of the pole faces seemed unnecessary.

The aluminum vacuum chamber has been fitted with baffles at 30°, 60°, 108°, 146°, 194°, and 224° from the source position (Fig.1), which define a maximum radial focusing angle of 0.1 radians and a maximum axial focusing angle of 0.16 radians. Tests using the Th F line have shown (4) that the instrument gives 0.45% and 0.21% resolution with a nominal transmission of 0.5 and 0.25% respectively. The true transmission, when losses due to counter window and third order defocusing terms are considered, is perhaps half of these figures.

The source and detector end plates of the vacuum chamber have been fitted with sliding brass gates (Fig. 2) so that the source and detector may be moved in and out of position, and thus changed without destroying the vacuum.

In this work, a great deal of effort was expended on the development of a low background coincidence geiger detector which has proven very satisfactory in the study of weak electron peaks. Improvements have also been made in the method of measurement of the magnetic field. This thesis deals with these developments and their application to a study of the decay scheme of In^{114}.

2. EXPERIMENTAL WORK

(i) Coincidence Detector

Since the electron image at the detector of a large source might be as great as 12 cm. in the z direction by 2 .5 cm. in the r direction, it was felt necessary to have a detector with a large sensitive area. A cylindrical geiger counter of diameter 4.13 cm and length 13.95 cm was constructed with a side window 1.42 by 7.62 cm(4). This counter is of necessity rather large, and has a cosmic background rate of about 40 counts per min. which makes the spectrometer useless for the study of weak electron peaks and sources of low specific activity.

Because of the limitations imposed on the spectrometer by this counter, a new geiger detector was designed to reduce the natural background rate (Fig. 3). It consists of two geiger counters sharing a common filling, and arranged so that with the detector in position, they lie on the circumference of a circle of radius 50 cm. Electrons entering the window pass through both counters, initiating coincident pulses which are detected by an N.R.C. Rossi type coincidence circuit of resolving time 2μ seconds. This detector has a natural background of 4 counts per min.

Voltage to both counters is supplied by an N.R.C. positive H.T. supply through a filter box, and the pulses are taken from the counter wires at the bottom end of a 1 megohm load resistor. The geiger pulses are fed through coaxial cable to a two stage RC coupled preamplifier (Fig.4) which uses a IN 34 crystal diode for a first stage input grid-leak, thus eliminating any positive overshoot at the grid of the 6AU6. The geiger pulses being of the order of 1/4 volt, the amplification of the first stage is nearly linear. The bias and load of the final stage are arranged so that small positive input drives the 6AH6 to saturation thus insuring a steep leading edge and also equalizing the output pulses. The pulses are observed to be as sketched in Fig. 4 when the counter H.T. is 25 volts below the geiger region, and do not change their shape appreciably throughout the whole plateau. The total current drawn by the preamplifiers is 15 ma.

The chief difficulty in bringing this detector into operation was encountered in the window and its mounting. It was necessary to stretch a thin plastic window of the type developed by N. J. Campbell(5) between two thin, flat, brass plates with matching grills, and to mount this assemply in such a way as to provide a vacuum tight seal. The following technique was used. The plastic is fastened to the outside brass plate with "Armor Coat" rubber cement, which adheres well to both substances, Fig. 5(a). A thin film of Apiazon "N" stop-cock grease on the inner brass plate next to the window completes the seal if the plates are kept firmly pressed together. The gasket beneath the holder is greased sparingly, and on one side only, so that it does not slip toward the center when under pressure.

This technique serves the purpose but is not entirely satisfactory. It is recommended that a new holder be designed which will enable the windows to be made much thinner and if possible eliminate the need for the rubber cement. Also it would be advisable to obtain a grade of gasket rubber with more uniform thickness and surfaces than that now in use.

To avoid contaminating the filling every possible precaution should be taken to keep surfaces next to the sensitive volume of the detector free from anything which has an appreciable vapour pressure. Such contamination causes a decrease in the counting rate with time. It was found advisable to clean the gaskets with soap and water since more active solvents such as carbon tetrachloride or ethyl ether were absorbed in the rubber and later affected the filling.

Extreme care should be taken at all times to keep the interior surfaces and wires of the detector free from all dust, grease, and wax, which can seriously affect the performance of the counters. If it becomes necessary to clean the inner surfaces, the detector should be soaked in a strong soap solution and the surfaces scrubbed, then rinsed with water, ether, water and alcohol. The center wires, if removed, should be flashed before reinstallation and soldered in when cool but under tension.

With voltage on both counters and using a standard counter filling of 1 cm of alcohol to 9 cm of argon, it was found that the individual plateaus were very steep and had an operating range of only 100 volts. However, these plateaus were quite usable when voltage was applied to one counter only. That this phenomenon was due to an interaction between the counters themselves, and not to the common H.T. supply was established by using separate supplies and plotting counts on the first counter against the voltage on the second as shown in Fig. 5(b). If the two counters were operating independently one would expect a horizontal linear plot instead of that shown.

By using a filling of 2 cm alcohol and 8 of argon, it was found possible to get plateaus of length 150 volts with a slope of 10 to 15% per 100 volts. This improvement is no doubt due to elimination of photon crossfire between the counters through the increased absorbing action of the alcohol vapour. Typical plateaus are shown in Fig. 5(c).

(ii) Magnetic Field Measurements

Because of the hysteresis effect in the iron of the beta spectrometer magnet, the field strength is not a linear function of the magnet current, making it necessary to have some device for measuring the field strength.

A flip coil and a critically damped galvanometer (L & N Type R) with a period of 7.15 sec. and a scale distance of 2 meters are currently being used for this purpose. The scale has been found to be linear within 0.6% over all ranges of deflections. The sluggishness of the critically damped galvanometer adds greatly to the ease with which deflections may be read, and makes zeroing much simpler. These two factors easily compensate for any loss in sensitivity due to over-damping.

The flip coil consists of 100 turns of #36 copper wire wound on a 2 inch by 2 inch bakelite form, and tapped at 70, 45, 25, and 10 turns. The shaft on which the coil is mounted is a 3/8 inch diameter stainless steel rod, which passes through two ½ inch thick brass plates drilled to give a firm fit, and placed 3 inches apart. The whole assembly is rigidly clamped in position between the pole faces of the magnet. The coil is turned manually. The deflection ratio between the coils and the sensitivities in the present position are tabulated below.

TABLE I

	Sensitivity (gauss / mm.)	Flip ratio
100T	.0684	1.43
70T	.0476	1.58
45T	.0300	1.80
15T	.0167	2.50
10T	.00668	

For any one run the magnet current is linear with the field over fairly large ranges. By plotting deflection versus magnet current, a straight line is obtained which serves to average out the poor readings. By this method the deflections may be estimated to 1 part in 1000. Calibration of the flip coil is made by doing a careful run on internal or external conversion peaks of well known $H\rho$ Once the flip deflection corresponding to a line of known momentum is obtained, lines of unknown momentum are readily and accurately calculated, provided of course they are near a known calibration point.

(iii) Source Preparation

(i) Beta Sources

Calibration of the flip coil, mentioned in the previous section, creates the need for a number of long half-life sources with well known gamma rays. To fill this need a method of beta source preparation has been devised, so that the sources may be safely stored, or mounted in the spectrometer for calibration or investigation purposes.

The source holder consists of two brass rings with bevelled inner edges, machined to fit snugly together. Glyptol cement is applied to the inner surfaces, and a thin plastic window, of the same material used in detector windows, is stretched and clamped between them. The bevelled inner edges serve to hold the window more securely, and also to position it in the proper source position. A line of active solution is then placed on the window and evaporated to dryness. The source may be mounted in the spectrometer by two small screws.

Since all indium salts are very hygroscopic, the In^{114} beta source could not be prepared in this way. However, it was found possible to obtain a source of uniform thickness by electroplating in the manner described below.(6)

The active metal was dissolved in concentrated sulphuric acid, evaporated to dryness and heated until no more acid fumes were observed. The white salt remaining was allowed to cool, then taken up in 10 ml. of distilled water and neutralized with 16 ml. of a solution containing 15 g. of borax and 75 g. of sodium formate per litre of water. Enough 90% formic acid was added to dissolve the precipitate and 0.1 ml. in excess. This was diluted to 33 ml. and electrolized with a current of 0.2 to 0.25 amps.

The cathode was a thin copper foil 3.0 cm by .5 cm, which had been cleaned in nitric acid and washed in distilled water. A revolving platinum anode was used. In the small volume of solution the electrolyte became weakened after about 10 minutes of current flow, slowing down the plating. By 30 minutes the plating ceased and the precipitate reappeared, making it necessary to add more formic acid. Both sides of the copper anode were plated, and the indium removed from one side by dilute nitric acid. The anode was then used as an In^{114} beta source. The plating was dark grey in colour and showed no tendency to flake off.

(ii) Gamma Sources

The photoelectric effect provides a useful method for gamma ray energy measurements. If thin metal foils or radiators are bombarded with gamma rays, photoelectrons will be ejected from the K shell and to a lesser extent from the L and other shells with energies equal to that of the gamma ray less the binding energy of the shell of origin.

Due to absorption in the radiator, these electrons will be in an energy band the width of which will be determined by the thickness of the radiator. Since our instrument has a resolution of about 1% for sources 1 cm wide, for best results the momentum spread of electrons from the radiator should be of the order of the momentum band admitted to the detector. Since the stopping power of matter is approximately 1 kev. for 1 mg/cm^2 of material(7), this indicates that for electrons of energy 1 Mev., the radiators should be in the range of 10 to 20 mg./cm^2 thick.

A lead foil of thickness 18 mg/cm^2 was prepared and attached to a 1/16 in. thick brass plate to form a rectangular radiator 3.0 cm by 1 cm. The brass plates were drilled so that when mounted in the spectrometer the radiator is in the proper source position. The brass plate serves to stop any betas which may be ejected by the gamma source, which is mounted on the opposite side of the plate from the radiator. It was found that the position of the gamma source had negligible effect on the position of the electron peak. For high energy gamma rays a uranium radiator 0.8 cm X 2.5 cm and 50 mg/cm^2 thick was available.

3. DATA AND RESULTS

In the decay of In^{114} a 50 day isomeric transition from the .192 Mev. level to the ground state is followed by a 72 second beta transition to the ground state of Sn^{114}. In addition to this dominant mode of decay, a few percent of the transitions go by K capture (8,9) to excited levels of Cd^{114}.

A thorough investigation of the gamma rays of In^{114} by external conversion has been made using 150 mg. of indium metal which had been given an activity of 150 mc. in the N.R.X. pile at Chalk River.

Since the spectrometer resolution used was less than 1%, the electron momentum spread caused by radiator thickness was considerably greater than the momentum band admitted to the detector. With this consideration the point of inflection of the high energy side of the peak should correspond very closely to electron energy with zero radiator thickness.

For energy measurements, comparison peaks of well known energies were needed for flip coil calibration. This was done by interchanging the sources and keeping the same source radiator geometry. The .556 and .722 Mev. cascade gammas of In^{114} were compared to the Cs^{137} .6614 Mev. gamma (10) and the 1.30 Mev. with the well known Co^{60} gamma rays at 1.1715 and 1.3316 Mev. (11).

The accuracy of the measurements show that the energy of the 1.30 Mev. gamma ray is too high for it to be a crossover transition. Careful comparison of the shapes of the 1.30 Mev. In^{114} and 1.33 Mev. Co^{60} peaks shows that the crossover transition is present as a weak unresolved peak corresponding to an energy of 1.271 Mev. Another weak gamma ray has been detected at an energy of .576 Mev. The data is presented in

Figs. 6 and 7 and the results are tabulated below.

TABLE II

Energies and Intensities of the Gamma Rays of In^{114}

Gamma Energy	Relative Intensity	Intensity in quanta per disintegration	Comparis Line
.192	------	.193	Internal conversion with Th F line
.5561 ± .001 Mev.	1.02	.036	
.5764 ± .003 Mev.	.035	1.2×10^{-3}	.66 14 Me in Cs^{137}
.7225 ± .001 Mev.	1.00	.035	
1.271 ± .006 Mev.	.01	3.5×10^{-4}	
1.300 ± .003 Mev.	.05	1.7×10^{-3}	1.3316 & 1.1715 Mev. in Co^{60}

The relative intensities of the four strongest gamma rays were determined by C. C. McMullen using our thin lens spectrometer which had been calibrated for intensity measurements by N. S. Campbell(5). These intensity estimates involve the use of Deutch's formula(12) and a knowledge of the variation of photoelectric crossection with gamma energy. The intensity of each gamma ray was corrected for self absorption in the source and in the brass source cover. The quantum yields for the .556, .722 and 1.30 Mev. radiations were determined by comparison with the .192 Mev. line using the known total internal conversion coefficient of 4.2.(13). Since we did not measure the .192 Mev. radiation by external conversion, it was impossible to determine the quantum yields from our measurements alone. However, the relative intensities as presented in Table II check closely with those obtained by McMullen. For the two weaker gamma rays first observed in this work, a direct comparison of peak heights was sufficient to establish the intensities. The quantum yields presented in the table represent a combination of our work and McMullen's.

With these results we can define excited states in Cd^{114} at energies .556, 1,278 and 1,856 Mev. The decay scheme is shown in Fig. 8. Using a fast coincidence circuit and lead absorption, coincidences have been found between the 1.30 and .556 Mev. gammas(14) giving further support to this scheme. A search for the 1.85 Mev. external conversion line using both Pb and U radiators has been unsuccessful.

An In^{114} beta source of strength about 1 mc. was prepared by electroplating as outlined previously in IIC. The internal conversion lines of the .556, .722 and 1.30 gamma rays were not detected because of the strong background of the beta continuum which extends to 1.98 Mev. Using .5% resolution we have some very tenuous evidence for a bump on the beta continuum at an energy which corresponds to the 1.85 Mev. line (Fig. 9).

From angular correlation measurements reported by R. J. Donnelly(14), there is some evidence to support the view that this is a 0 0 transition which is forbidden for from our measurements alone. However, the relative intensities as presented in Table II check closely with those obtained by McMullen. For the two weaker gamma rays first observed in this work, a direct comparison of peak heights was sufficient to establish the intensities. The quantum yields presented in the table represent a combination of our work and McMullen's.

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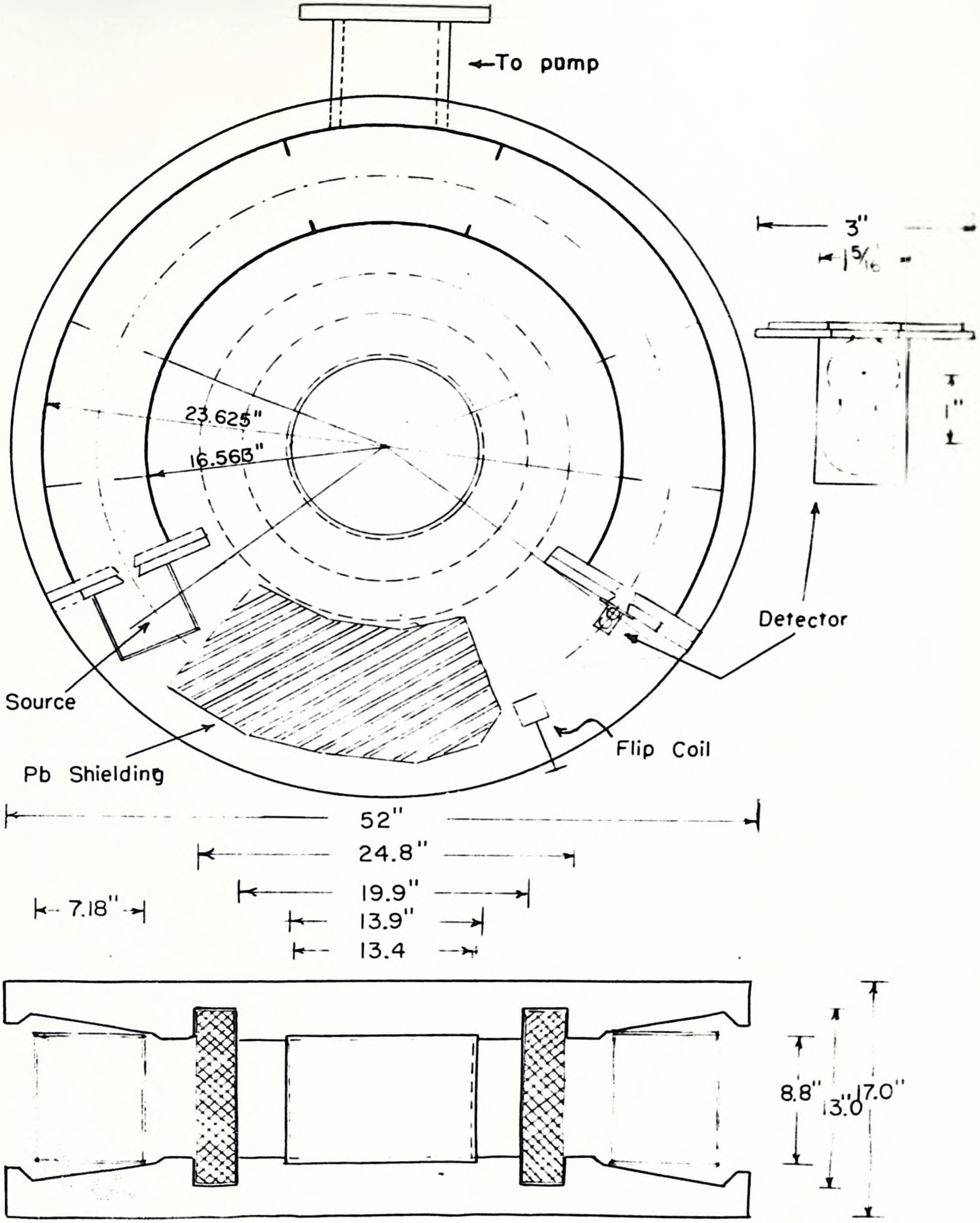


50 Cm Double Focusing Spectrometer

FIGURE 1

SIEGBAHN SPECTROMETER
VACUUM CHAMBER END PLATES

(Source and Detector end plates are identical except for hole in center)

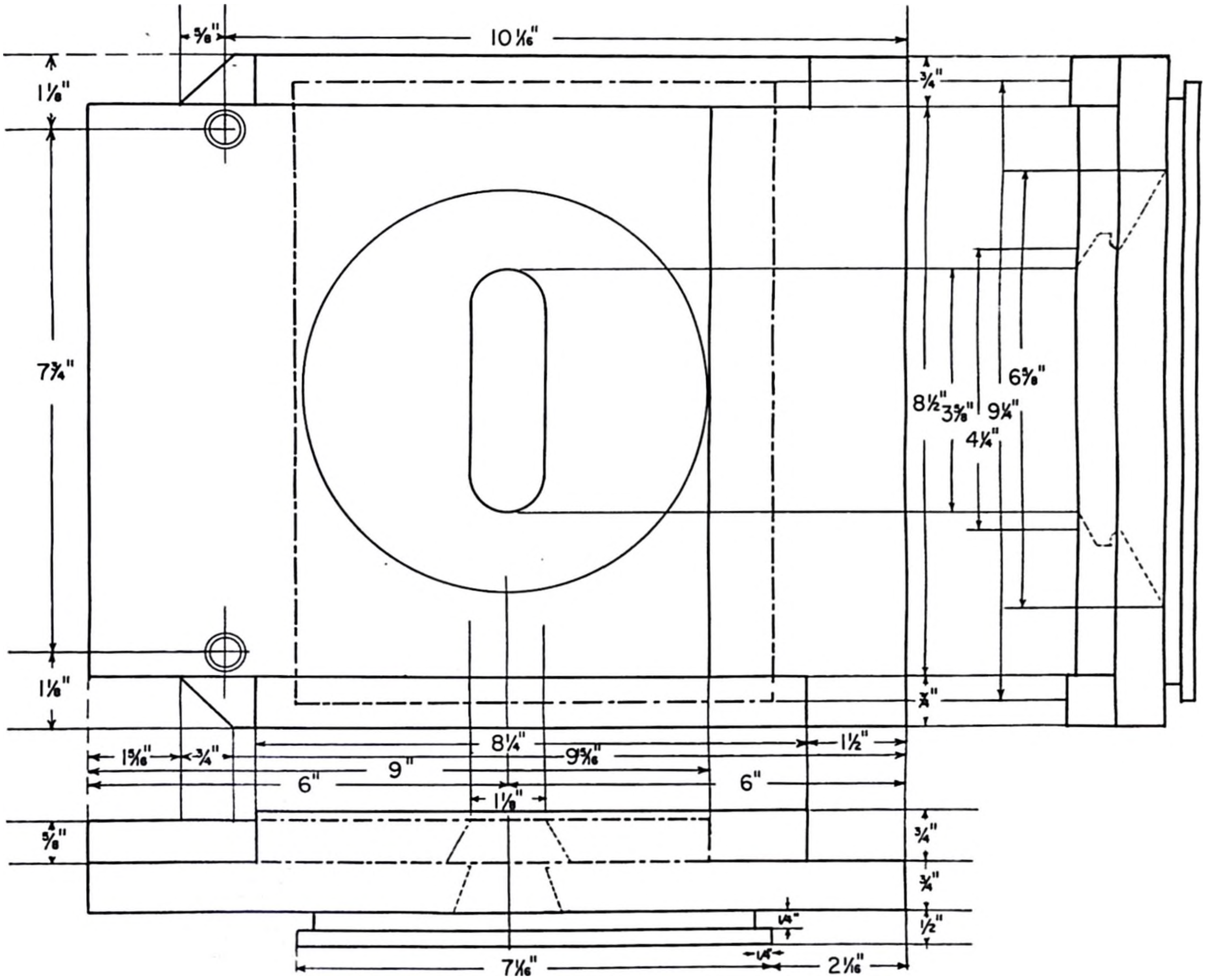


FIGURE 2

GEIGER COINCIDENCE DETECTOR

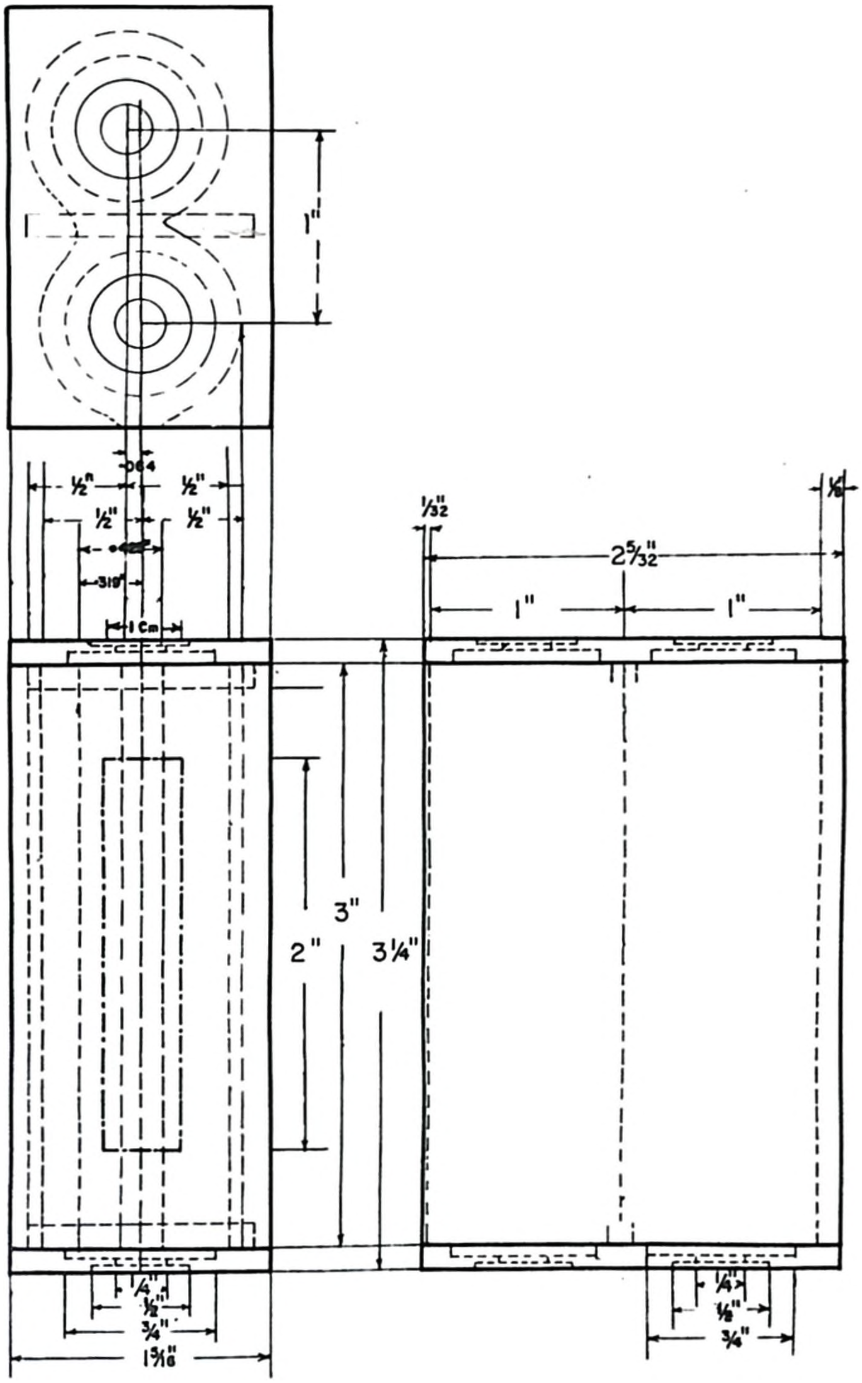


FIGURE 3(a)

COINCIDENCE DETECTOR FACE PLATE

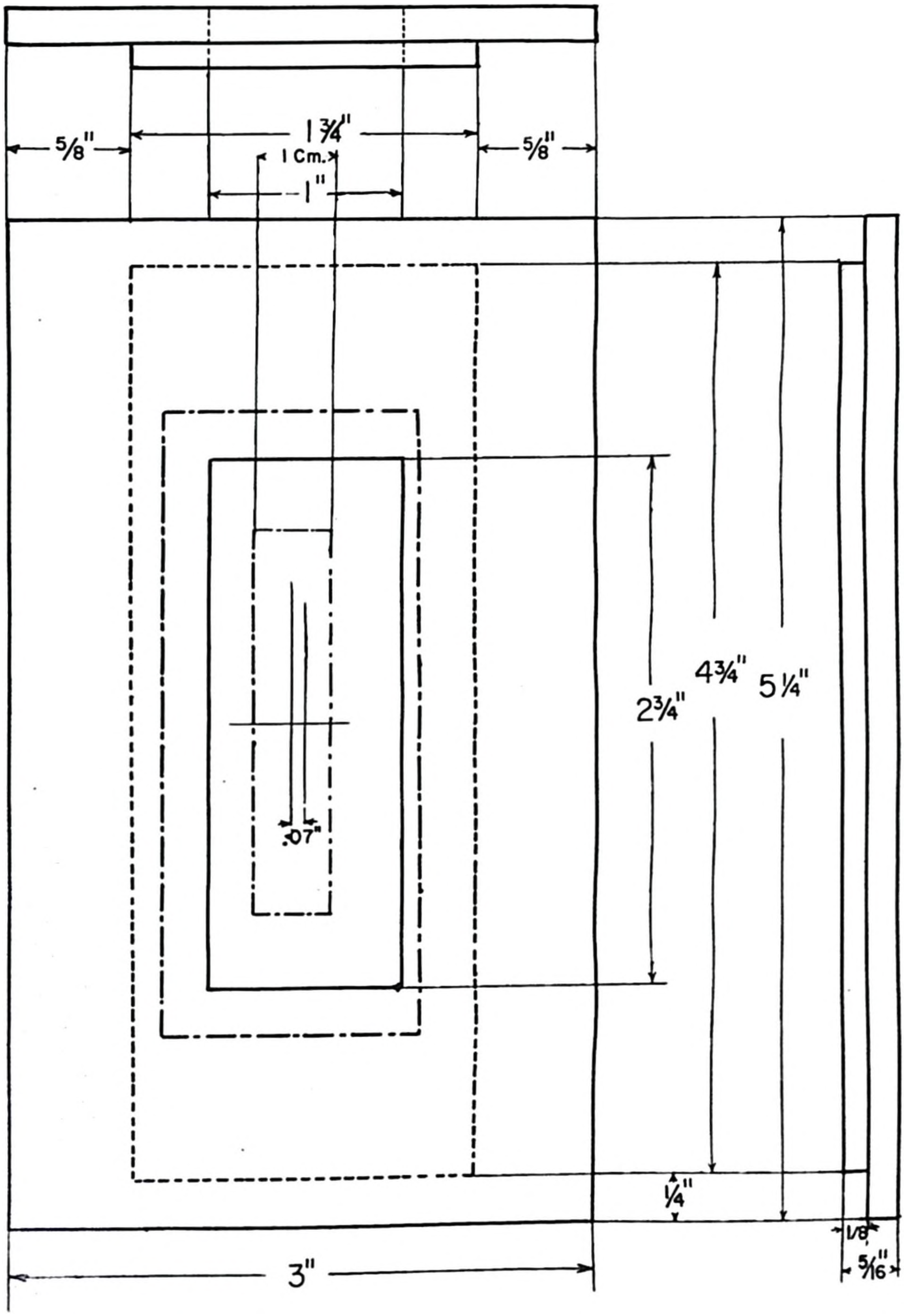
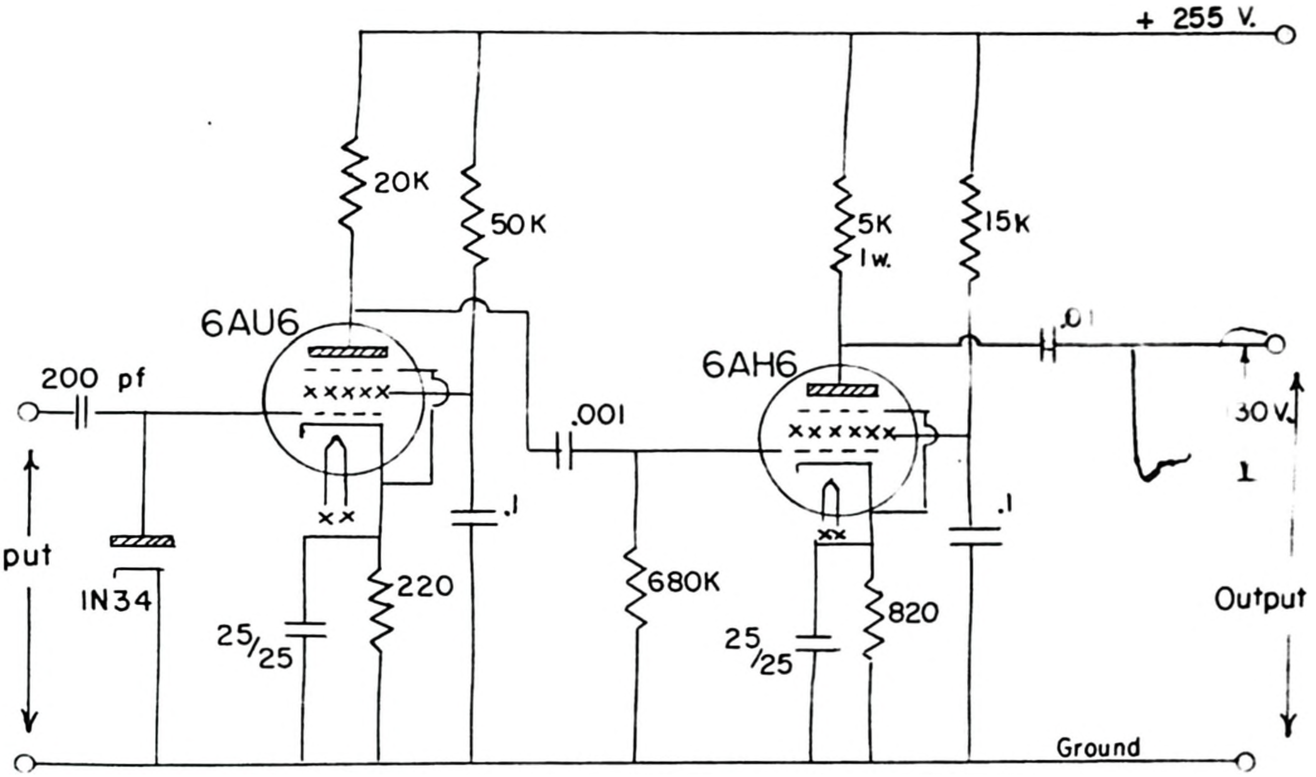


FIGURE 3(b)

Preamplifier
for
Coincidence Geiger Detector



Preamps identical for both counters

FIGURE 4

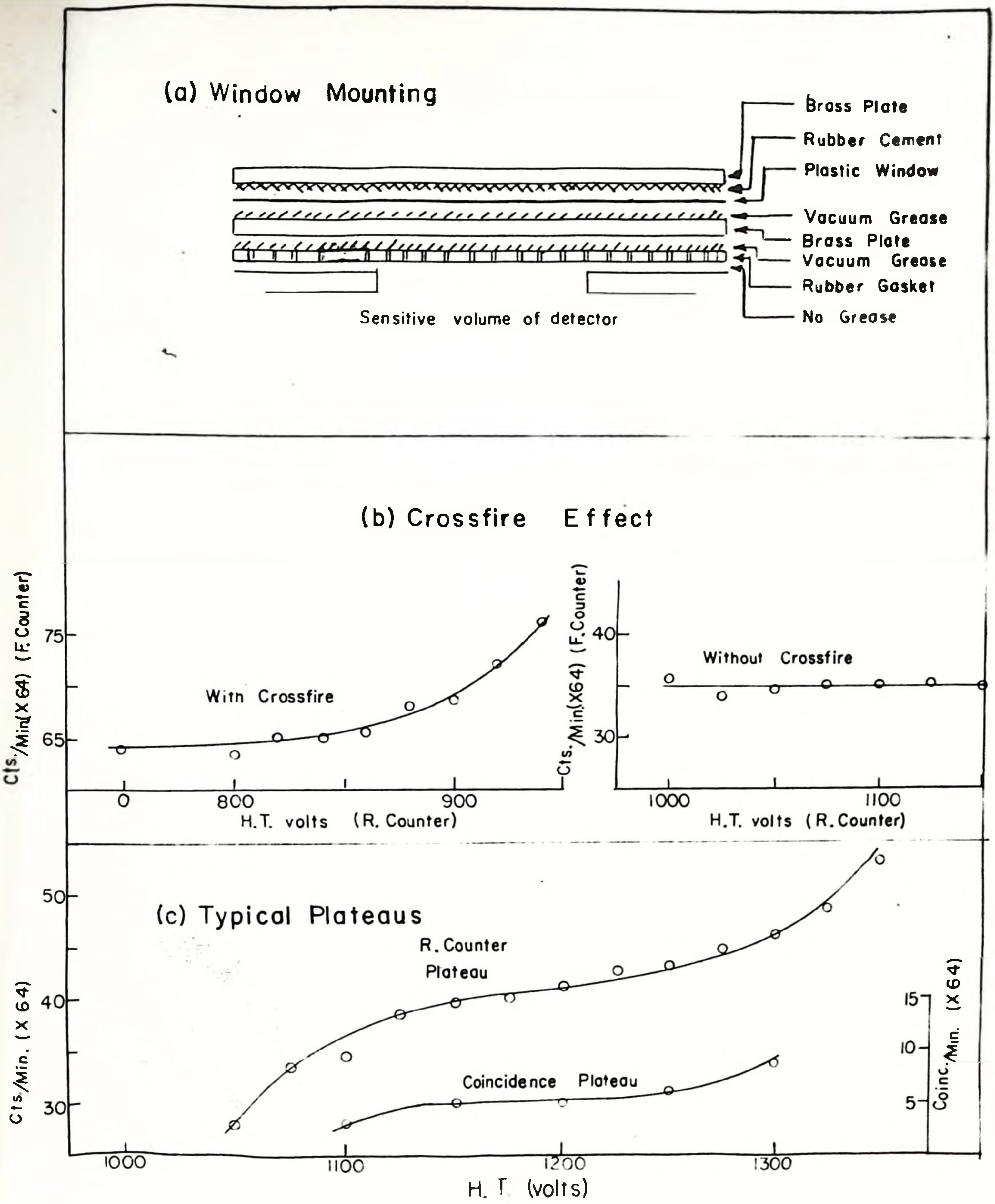

(a) Window Mounting
Brass Plate
Rubber Cement
Plastic Window
Vacuum Grease
Brass Plate
Vacuum Grease
Rubber Gasket
No Grease
Sensitive volume of detector
(b) Crossfire Effect
Cts./Min.(X64) (F. Counter)
75
65
With Crossfire
0
800
900
H.T. volts (R. Counter)
Cts./Min.(X64) (F. Counter)
40
30
Without Crossfire
1000
1100
H.T. volts (R. Counter)
(c) Typical Plateaus
Cts./Min. (X 64)
50
40
30
R. Counter Plateau
Coincidence Plateau
Coinc./Min. (X 64)
15
10
5
1000
1100
1200
1300
H.T. (volts)

FIGURE 5

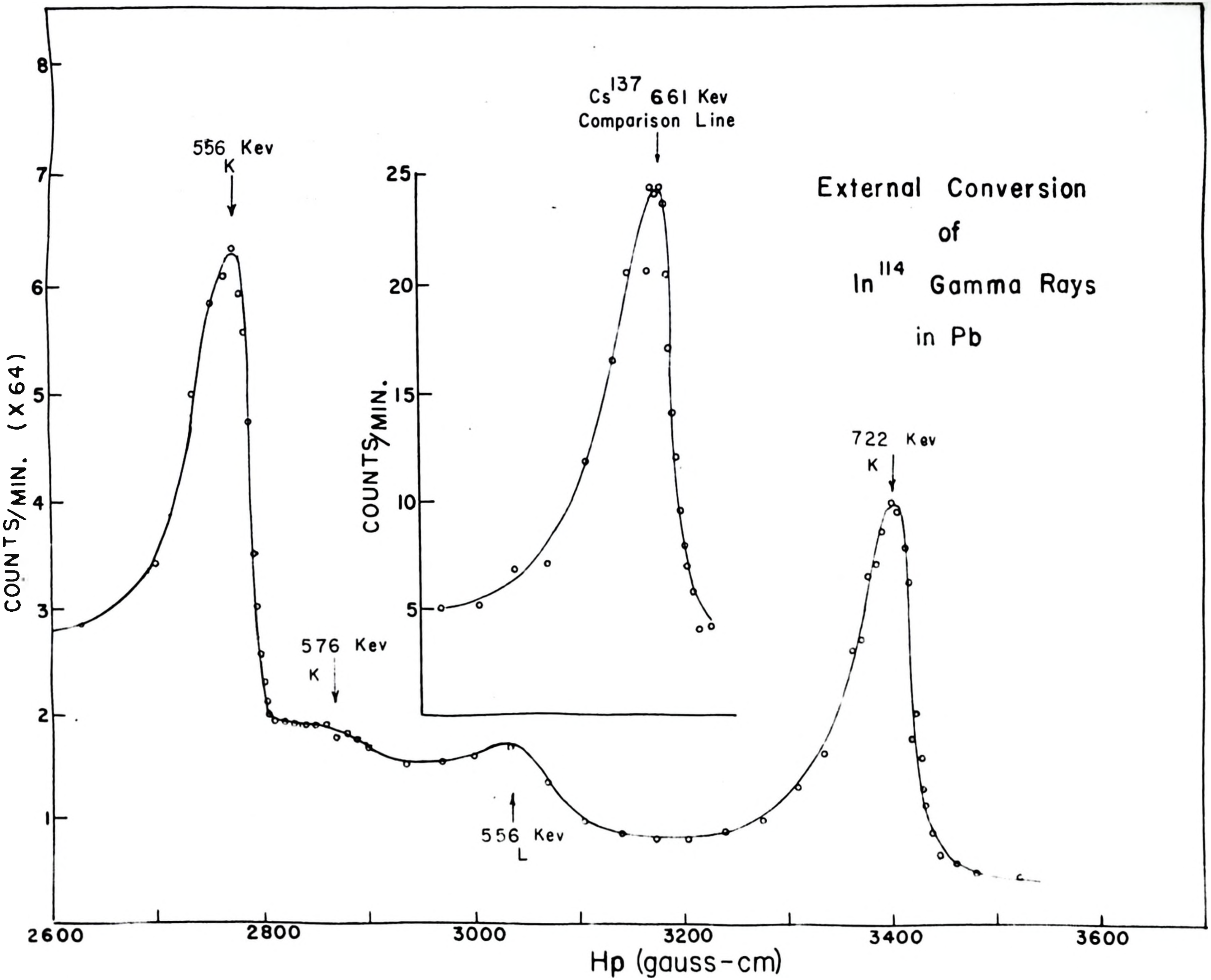

External Conversion of In^{114} Gamma Rays in Pb
556 Kev K
576 Kev K
556 Kev L
722 Kev K
Cs^{137} 661 Kev Comparison Line
COUNTS/MIN. (X 64)
COUNTS/MIN.
Hρ (gauss-cm)
2600
2800
3000
3200
3400
3600
1
2
3
4
5
6
7
8
5
10
15
20
25

FIGURE 6

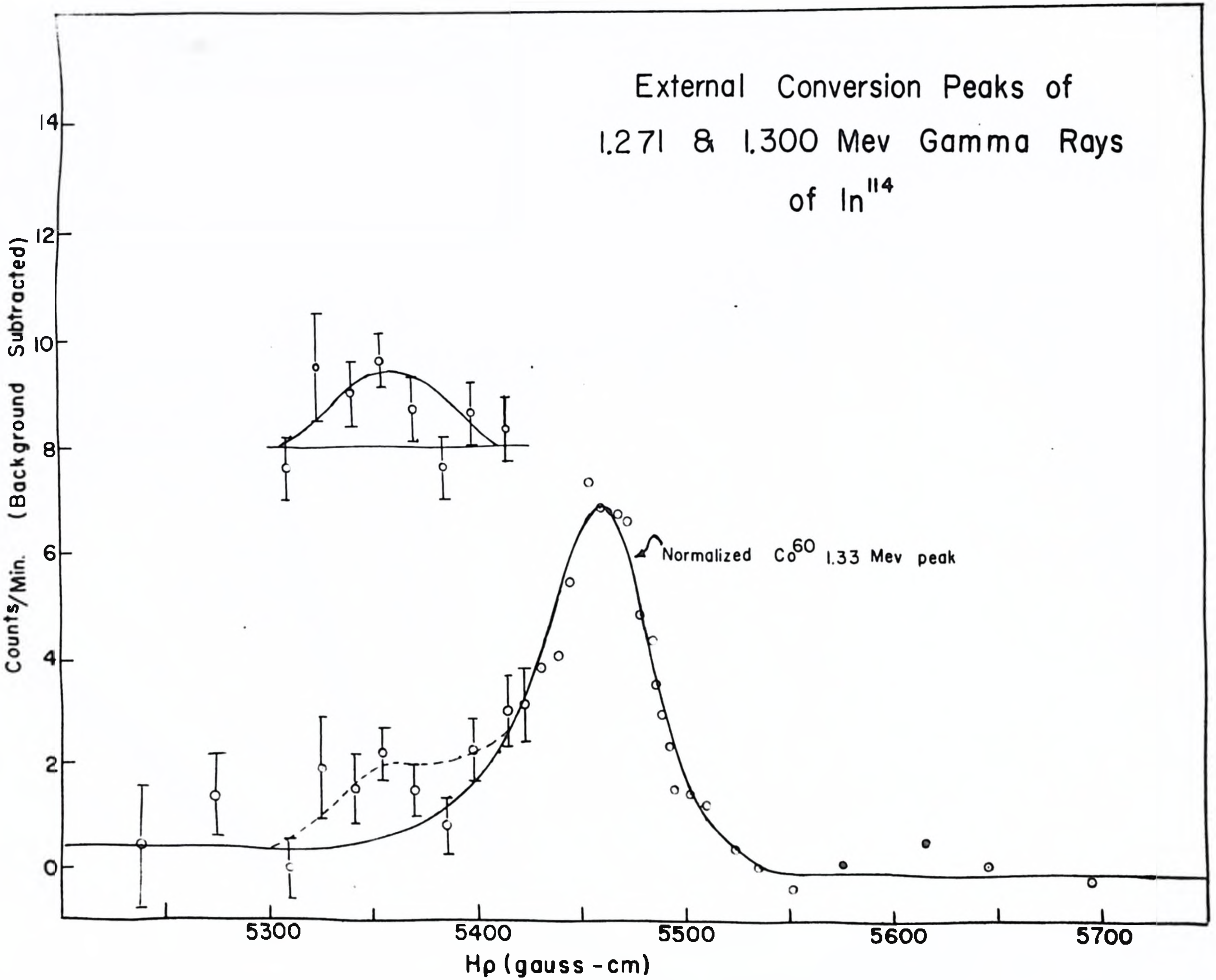

External Conversion Peaks of
1.271 & 1.300 Mev Gamma Rays
of In^{114}
Counts/Min. (Background Subtracted)
14
12
10
8
6
4
2
0
Normalized Co^{60} 1.33 Mev peak
5300
5400
5500
5600
5700
Hρ (gauss-cm)

FIGURE 7

Decay Scheme of In^{114}

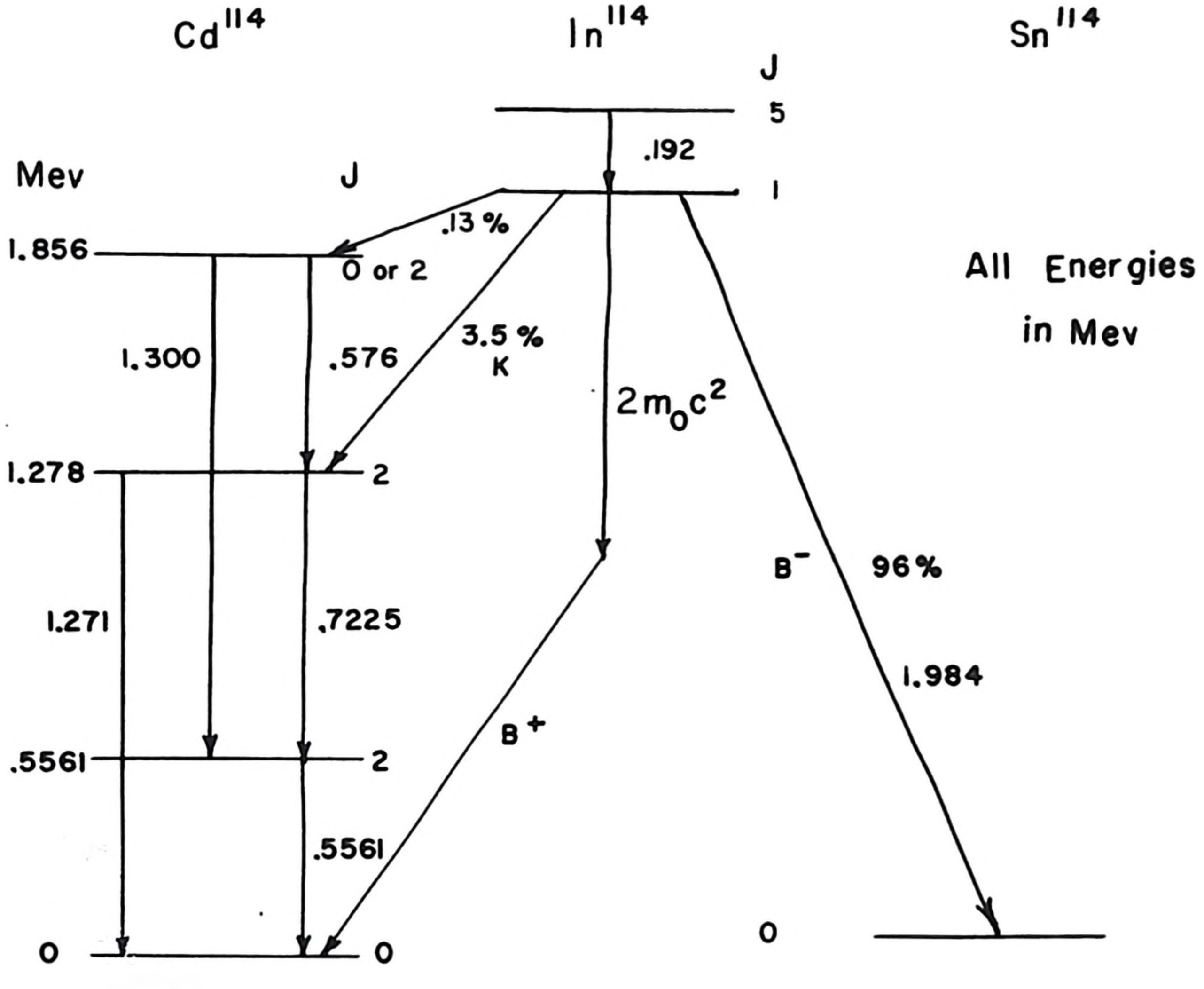


FIGURE 8

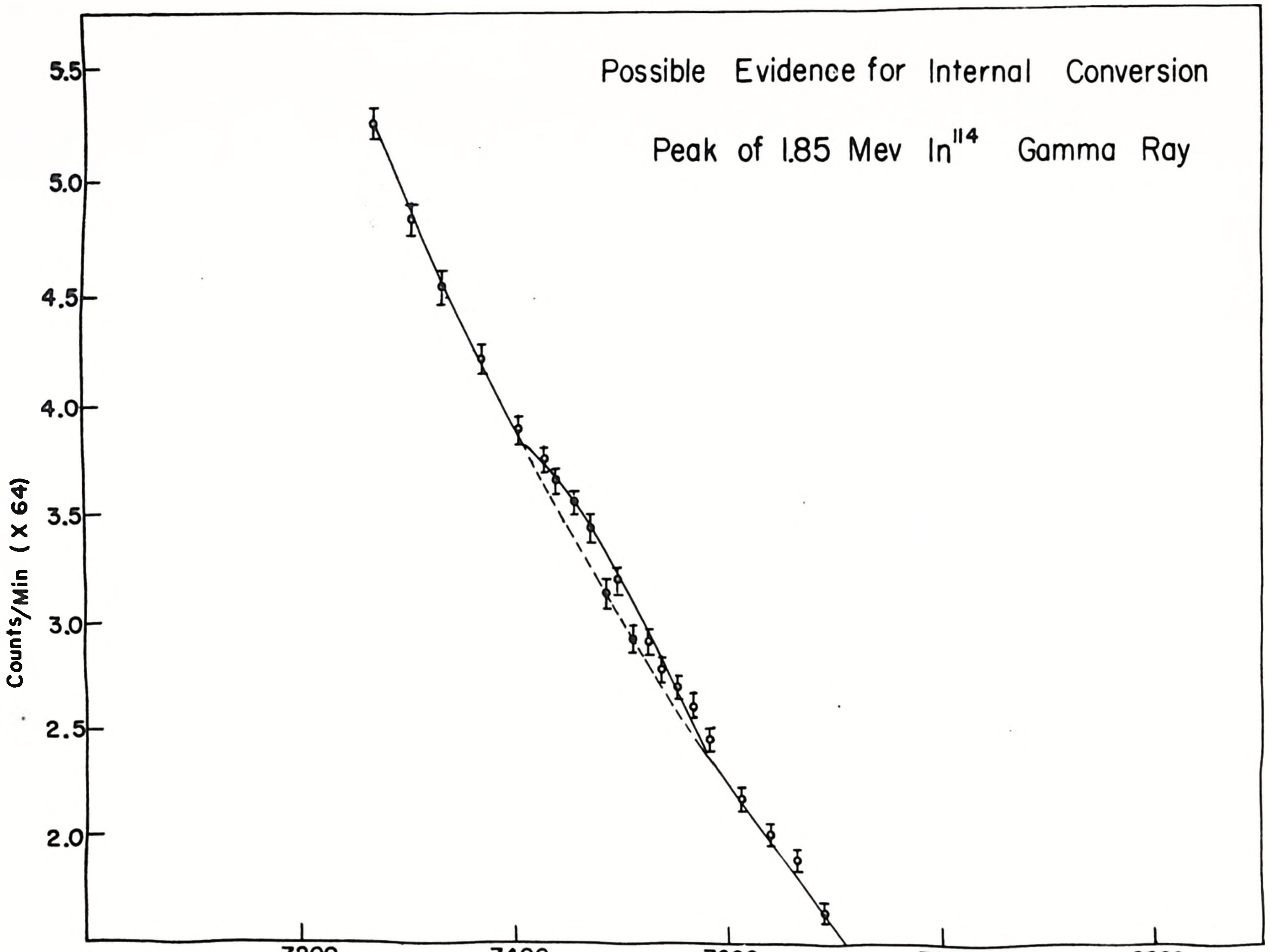

Possible Evidence for Internal Conversion
Peak of 1.85 Mev In^{114} Gamma Ray
Counts/Min (X 64)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
7200
7400
7600
7800
8000
Hρ (gauss-cm)

FIGURE 9

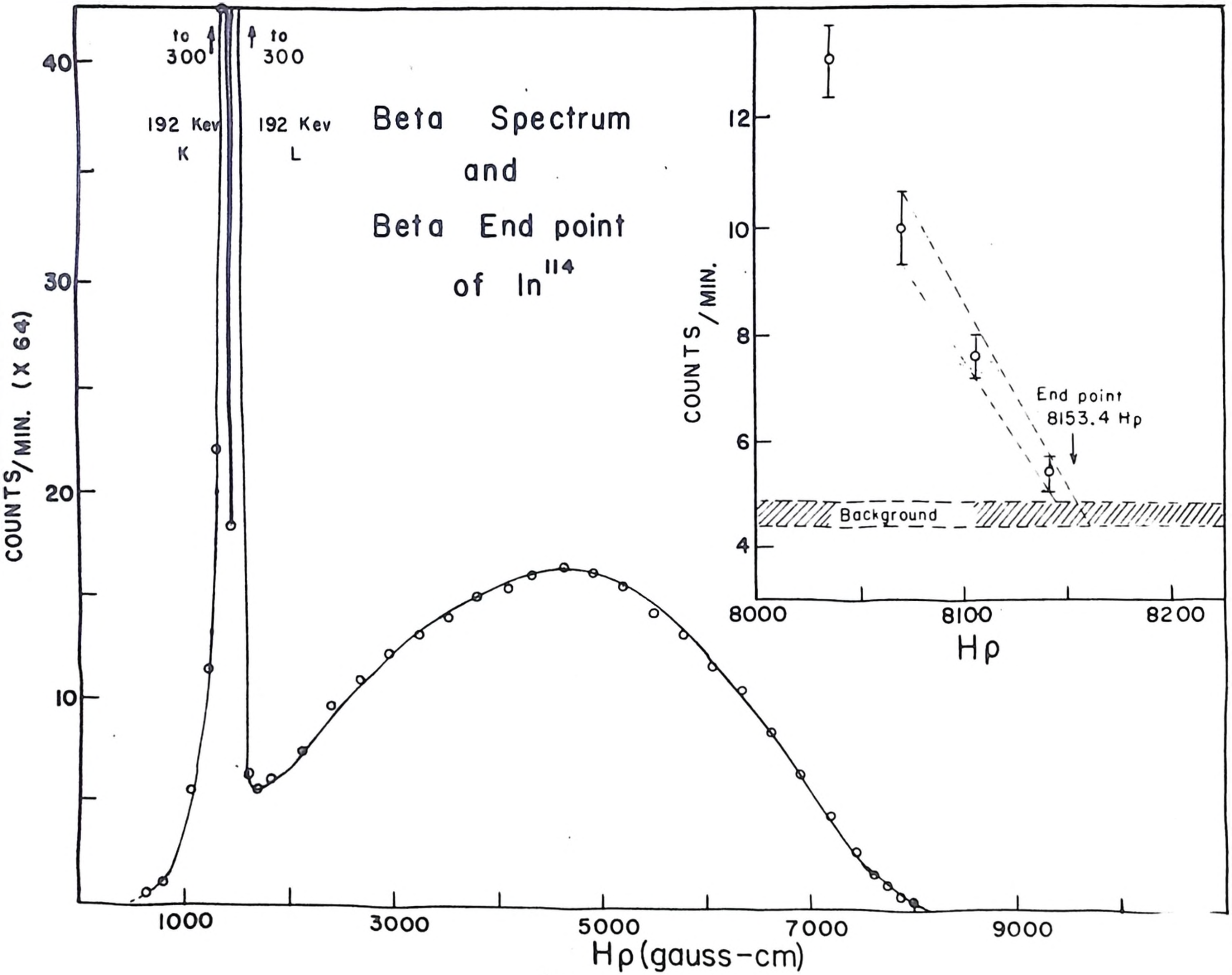

Beta Spectrum
and
Beta End point
of In^{114}
to 300
to 300
192 Kev K
192 Kev L
COUNTS/MIN. (X 64)
40
30
20
10
1000
3000
5000
7000
9000
Hρ (gauss-cm)
COUNTS/MIN.
12
10
8
6
4
End point 8153.4 Hρ
Background
8000
8100
8200
Hρ

FIGURE 10