DUAL DECAY OF In^{114}

AND A STUDY OF

MAGNETIC FIELD STABILIZATION

Dual Decay of In^{114}
and a Study of
Magnetic Field Stabilization

by

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SCOPE AND CONTENTS:

This thesis consists of two parts. Part A describes the investigation of the K-capture component in the decay of 50-day In^{114}.

Part B is the main part and deals with the construction and operation of an A.C. null method of measuring and controlling an inhomogenous magnetic field.

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INTRODUCTION

The stable isotopes of any element are bounded on both the low and high mass side by unstable nuclei. Those on the higher mass side decay by the emission of a negatron, (negative electron) which transforms the parent of nuclear charge z into a daughter of charge z + 1. Those in the low mass side decay by positron emission and K electron capture to a nucleus of charge z - 1. If the energy available is insufficient for positron emission, K or L-electron capture may still provide a means of decay. Some odd-odd nuclei, such as In^{114}, disintegrate by all three methods. Each of these processes may leave the daughter nucleus in any one of a number of excited states from which it is de-excited by gamma emission. Since there are often many such states energetically available, the decay scheme may become very involved.

Two very useful instruments for unravelling such decay schemes are the magnetic spectrometer and the coincidence circuit. The magnetic spectrometer is able to provide precise information concerning the energies and intensities of the gamma-rays, internal conversion electrons and beta spectra. With such information, it is very often possible to propose a reasonable decay scheme, but it is necessary to test it by carrying out beta-gamma and gamma-gamma coincidence experiments.

Both spectrometer and coincidence experiments have been conducted by the author to establish a mode of decay of In^{114}. This work is described in Part A of this thesis.

In order to obtain the best results possible from a magnetic spectrometer, it is necessary to control and measure the magnetic field very accurately. Part B describes an attempt to achieve the control and measurement of the field of our Siegbahn-type spectrometer to one part in 10,000.

PART A

THE ROLE OF THE 1.30 MEV. GAMMA-RAY IN THE DECAY OF In^{114}

I. Introduction

Since a K-capture component in the decay of In^{114} was discovered in 1949 by Boehm and Preiswerk (1) and Mei, Mitchell and Zaffarano (2), many physicists (3, 4, 5) have been interested in the decay of this nuclide. In particular, during 1953 and 1954 workers in this laboratory have made precise energy measurements of the gamma rays accompanying the decay of In^{114} and have used coincidence techniques to support their decay scheme and examine the angular correlation pattern. The energy values and intensities quoted by Johns and co-workers (5, 6) are as follows: 556 $\pm$ 1 kev. (3.6×10^{-2}), 576 $\pm$ 3 kev. (1×10^{-3}), 722 $\pm$ 1 kev. (3.5×10^{-2}), 1271 $\pm$ 6 kev. (3×10^{-4}) and 1300 $\pm$ 3 kev. (1.5×10^{-3}). These were interpreted as transitions between states in Cd^{114} of the following energies and spins: 0 (0 +), 556 kev. (2 +), 1278 kev. (2 +) and 1856 kev. (0 +). The spin assignment for the first three levels was consistent with the angular correlation data obtained here and elsewhere, but it should be pointed out that the data could equally well be reconciled with a 0 - 2 - 4 cascade. Their 0 - 2 - 2 choice was made because of the presence of the weak 1271 kev. crossover transition; other workers, whose energy measurements were only good to 2% had assumed that the 1300 kev. line was the crossover.

In 1954 Lu, Kelly and Wiedenbeck (7) using scintillation crystals in the summing technique, found no evidence for the 1856 Kev. level. The existence of this level and the 2+ spin assignment to the 1278 kev. level also created difficulties in interpretation of the γ-ray capture results of Kinsey and Bartholomew at Chalk River and Motz at Brookhaven.

Following a discussion of these difficulties in Washington in the spring of 1955, Motz of Brookhaven, Steffen of Purdue University and workers from this laboratory agreed to reinvestigate the entire decay of this nuclide. We decided to repeat both our energy and coincidence measurements with the more refined techniques which had been developed in this laboratory since 1953.

II. Spectrometer Experiments and Results

The source was prepared by irradiating 1 gm of indium metal foil in position A (flux of 7×10^{12} n/cm^2/sec) for a period of 4 weeks in the Chalk River N.R.X. reactor. The dimensions of the foil were 0.5 cm by 2.0 cm and it was estimated to have an activity of 720 mc.

The gamma rays were examined by the external conversion technique using a 10 mgm/cm^2 uranium radiator (8) and a large double-focusing magnetic spectrometer (5). In order to obtain good statistics, it was necessary to count for several weeks. The instrument was calibrated with the 1331 kev. gamma of Co^{60} (9) externally converted in a 10.3 mgm/cm^2 uranium radiator.

Some of the data obtained is shown in Fig. 1 and the results of the measurements are presented in Table I. The agreement in energies between the present work and that previously carried out in this laboratory is excellent for the three stronger gamma rays. The intensities of these lines were measured relative to the 556 kev. line whose absolute intensity had been measured by Cox (6). Despite a long period of careful investigation no evidence was found for the existence of either of the 2 weak radiations at 576 and 1271 kev. previously reported.

TABLE I

ENERGIES (KEV)		INTENSITY	
Cox et al	Present Work	Cox et al	Present Work
556.1 ± 1.0	557.1 ± 1.0	3.6×10^{-2}	3.6×10^{-2} *
576.4 ± 3.0	Not measured	1×10^{-3}	$< 3 \times 10^{-4}$
722.5 ± 1.0	Not measured	3.5×10^{-2}	3.5×10^{-2}
1271 ± 6	Not measured	3×10^{-4}	$< 1 \times 10^{-4}$
1300 ± 3	1299 ± 2	1.5×10^{-3}	$2.0 \pm 0.4 \times 10^{-3}$

* Cox's value taken as a reference.

The dotted lines in Figure 1 show the profiles corresponding to the upper intensity limits given in Table I. These results show clearly that the decay scheme proposed by workers in this laboratory is in error. The absence of the 576 kev. line makes suspect the existence of the 1856 kev. level and the role assigned to the 1300 kev. gamma ray. The absence of the 1271 kev. line indicates that the 2+ spin assignment to the 1278 kev. level is almost certainly incorrect. Therefore it was decided to carry out coincidence experiments to settle the role of the 1300 kev. radiation in the decay.

III. Coincidence Experiments and Results

The coincidence experiments were carried out by Ian Williams and myself, with the former carrying the main responsibility for the work. However, in order that the story be complete, his work and mine are being reported here.

The coincidence circuit used, consisted of two scintillation counters, each feeding a single channel pulse-height analyser built by Ian Williams (10) on a Chalk River design. The outputs of the analysers were fed to a coincidence circuit of 1 micro-sec. resolving time. For gamma detection, cylindrical NaI crystals 1" x 1 1/2" diameter were used, while anthracene crystals 1/4" thick were used for beta detection.

The gamma-gamma coincidence experiments to be described below show clearly that the 1300 kev. radiation is not in coincidence with the 556 kev. gamma-ray as previously reported (5). In these experiments the NaI crystals were covered with 6 mm of lead to reduce the contribution of the strong 192 kev. radiation accompanying the isomeric transition in In^{114}. Curve A of Fig. 2 shows the single channel spectrum in either gamma crystal when the source (a few micro-curies) is placed as close as possible to the crystal surface. On the basis of curve A, the intensity of the 1300 kev. radiation was about 12% of the 556 kev. radiation while the spectrometer measurements showed that it was only 4% of this radiation. The apparent increase in height of the 1300 kev. line was due to solid angle pile-up (556 + 722 = 1278), as was proved by moving the source away to reduce the solid angle . When this was done, curve B was obtained. It was felt that there might be a considerable bremsstrahlung contribution created by the stopping of the 2 Mev. betas in the lead absorbers. To check this point, a Y^{90} source was prepared and placed in the same geometry. Since Y^{90} emits no gamma rays and has a beta end-point of 2.3 Mev., its bremsstrahlung spectrum should be very similar to that of In^{114}. Curve C shows this spectrum. The intensity of the gamma peak between B and C checks quite well with the intensity obtained for the 1300 kev. line from the spectrometer experiments.

It was first suggested by Nussbaum and van Lieshout (11) that the first excited state in Sn^{114} should lie near 1200 kev. and it was natural to suspect that the 1300 kev. was due to the de-excitation of this level. C. C. McMullen of this laboratory (12) had found beta-gamma coincidences which could have been due to either transitions involving this level or to bremsstrahlung-beta coincidences. With pulse height selection, it was possible for us to focus the gamma detector uniquely on the 1300 kev. radiation and thus to repeat his experiment with the bremsstrahlung contribution reduced to a negligible amount.

The gamma-gamma coincidence spectrum, obtained when the fixed channel was set on the 722 kev. photopeak and the window of the other spectrometer was moved across the spectrum, is shown in curve D. Curve E represents the results obtained in the same arrangement with the fixed channel set on the 1300 kev. photopeak. Curve F represents the spectrum of 556-1300 kev. coincidences expected on the basis of the measured intensity of the 1300 kev. radiation and the previously reported decay scheme. Obviously the 1300 kev. gamma-ray is not in cascade with the

556 kev. line and therefore it must be placed elsewhere in the decay scheme.

When the gamma counter was set on the 1300 kev. photopeak and the beta detector scanned across the beta spectrum, true beta-gamma coincidences were observed up to 710 kev. When a Y^{90} source of the same strength was used in the same arrangement no true beta-gamma coincidences were observed. The results for In^{114} are presented in curve G in the form of a Fermi plot. Within the limitations imposed by the rather poor statistics, the spectrum seems to be well behaved with an end-point at 710 $\pm$ 50 kev. During the month required to build up the necessary statistics, the instrument was calibrated at frequent intervals with the 661 kev. gamma-ray from Cs^{137}.

IV. Discussion and Conclusions

The experiments described above show that:

(1) The 576 and the 1271 kev. radiation are much weaker than reported and probably do not exist.

(2) The 556 kev. gamma-ray is in coincidence with the 722 kev. radiation and not in coincidence with the 1300 kev. gamma-ray.

(3) The 1300 kev. radiation arises from the de-excitation of the first excited state in Sn^{114}.

On the basis of these experiments and earlier work, a decay scheme is presented in Fig. 2. The 4+ assignment to the 1278 kev. level is based on the absence of the crossover transition. Recent experiments of Brazos and Steffen have confirmed our conclusion that the spins of the three levels in Cd^{114} are 0-2-4 with even parity and have shown that the 1278 kev. level must be fed from the 5+ state of In^{114}.

Experiments by Motz (13) have led to essentially the same conclusions. Everyone now seems to be happy with this description of the decay of In^{114}. These results are consistent with those of capture gamma-ray studies and with the "summation" experiments of Lu et al. In addition, the position of the first excited state in Sn^{114} at 1300 kev. has been established. On the basis of experience with other even-even nuclei, this state almost certainly has a spin 2 and even parity.

An account of our experiments has been published in the Canadian Journal of Physics (14). A reprint is appended.

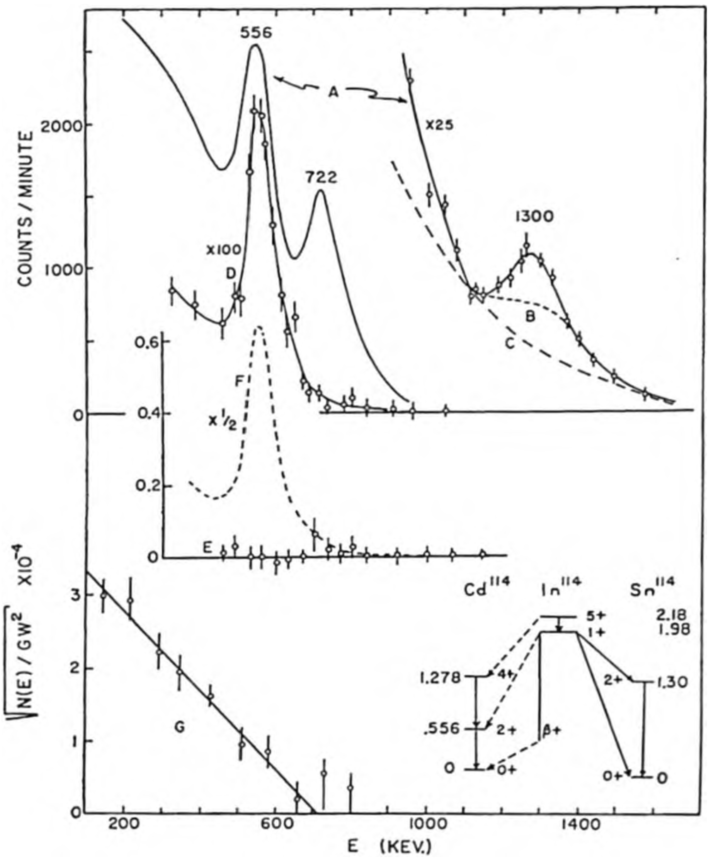
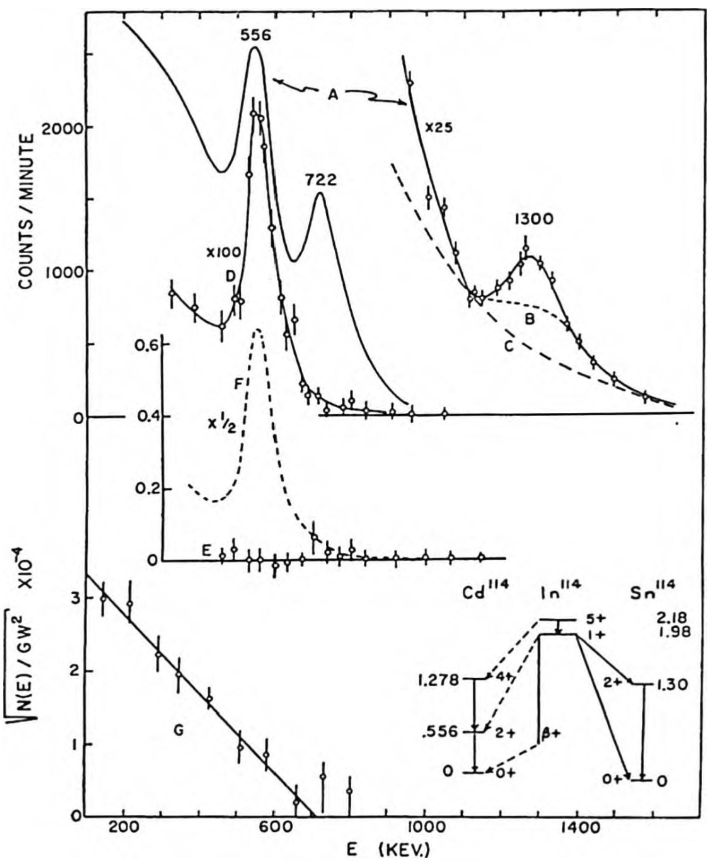


FIG. 1. Gamma–gamma and beta–gamma coincidence spectra of In^{114}.

distribution in each of the single spectrometers. The 1300 kev. peak is much augmented in this spectrum by solid-angle pile-up. Curve B shows the true height of this peak obtained by reducing the solid angle to 1% of the value used for Curve A. An estimate of the intensity of the 1300 kev. radiation based on Curve B is in good agreement with the value obtained by external conversion. Curve C represents the bremsstrahlung spectrum produced by a source of Y^{90}, a pure beta-ray emitter with approximately the same end-point as In^{114}. It is clear that the sharply-falling background of Curve A above 1.1 Mev. is due to bremsstrahlung caused by stoppage of 2 Mev. beta-rays in the lead absorber.

The gamma–gamma coincidence spectrum obtained when the fixed channel was set on the 722 kev. photopeak and the window of the other spectrometer was moved across the spectrum is shown in Curve D. The results obtained in the same way with the fixed channel set on the 1300 kev. photopeak are presented in Curve E. The data for the latter case have been corrected for a small chance contribution which was at no point in the spectrum greater than 0.02 counts/min. These curves show clearly that the 556 kev. gamma-ray is in coincidence with the 722 kev. radiation and not in coincidence with the 1300 kev. radiation. Curve F represents the spectrum of 1300–556 kev. coincidences expected on the basis of the measured intensity of the 1300 kev. radiation and the decay scheme reported in our previous work. It is clear that less than 1.5% of the 1300 kev. gamma-rays can be in cascade with the 556 kev. radiation.

The spectrum of beta-rays in coincidence with the 1300 kev. radiation was studied in the same way as the gamma–gamma coincidence spectrum described above. For this purpose, one of the NaI(Tl) crystals was replaced by an anthracene crystal covered with 25 mgm./cm.^{2} of aluminum to prevent detection of the abundant conversion electrons from the 192 kev. transition. The beta spectrum was scanned with a 30 kev. window while the fixed channel



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A Fermi plot of the β–γ coincidence spectrum, corrected for chance, is presented in Curve G. The spectrum appears to be well-behaved and has an end-point of 710 ± 50 kev. Both the beta and gamma spectrometers were calibrated frequently during the month required to build up reasonable statistics, using Cs^{137} sources in the indium source position. Drifts in the electronics over this period did not change the calibration by more than 50 kev.

A decay scheme proposed on the basis of the above experiments is presented in Fig. 1. The spins of the three levels in Cd^{114} have recently been uniquely determined as 0–2–4 through the polarization – angular correlation experiments of Brazos and Steffen (1955). Consequently the 1.278 Mev. level must be fed from the 5+ state of In^{114}. With the rejection of the 1.856 Mev. level originally proposed (Johns, McMullen, Donnelly, and Nablo 1954), this decay scheme is now concordant with the results of capture gamma-ray studies. K-capture transitions to the 556 kev. level of Cd^{114} are to be expected but seem to be weak.

It was originally pointed out by Nussbaum and Van Lieshout (1953) that there should be a beta-transition to an excited state of Sn^{114} of energy $\sim$1.2 Mev. and they set an upper limit on its intensity of 3×10^{-3} particles per disintegration. From our experiments, it is clear that this group has an intensity of 2×10^{-3} and an end-point of 700 kev. Such a transition has a log ft value of 5.5, characteristic of an allowed spectrum. Consequently, the 1.30 Mev. level in Sn^{114} represents the first excited state in that nuclide and almost certainly has spin 2 and even parity.

A recent communication from Dr. Motz of the Brookhaven National Laboratory indicates that he has arrived at essentially the same conclusions through an independent and somewhat different group of experiments.

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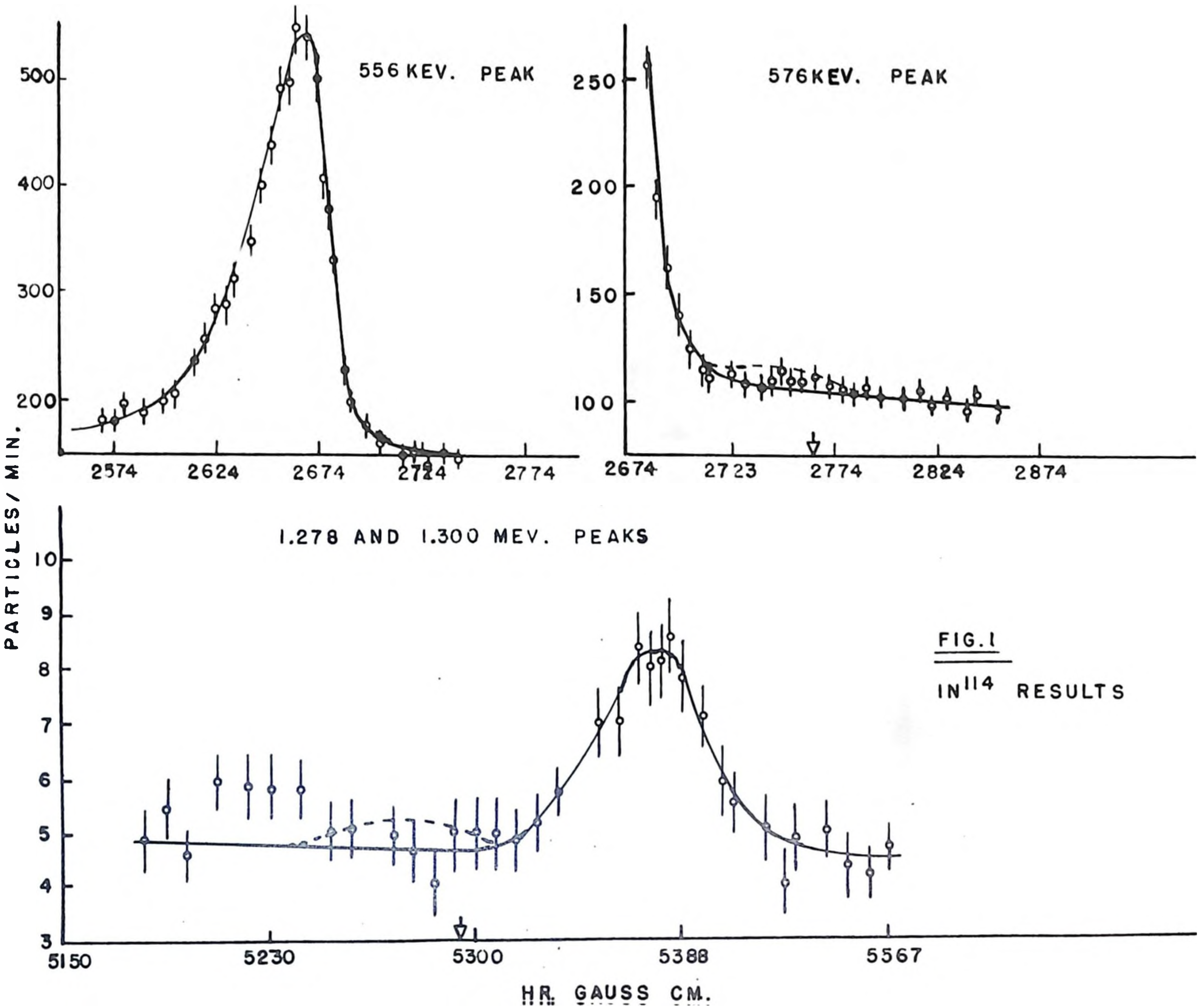
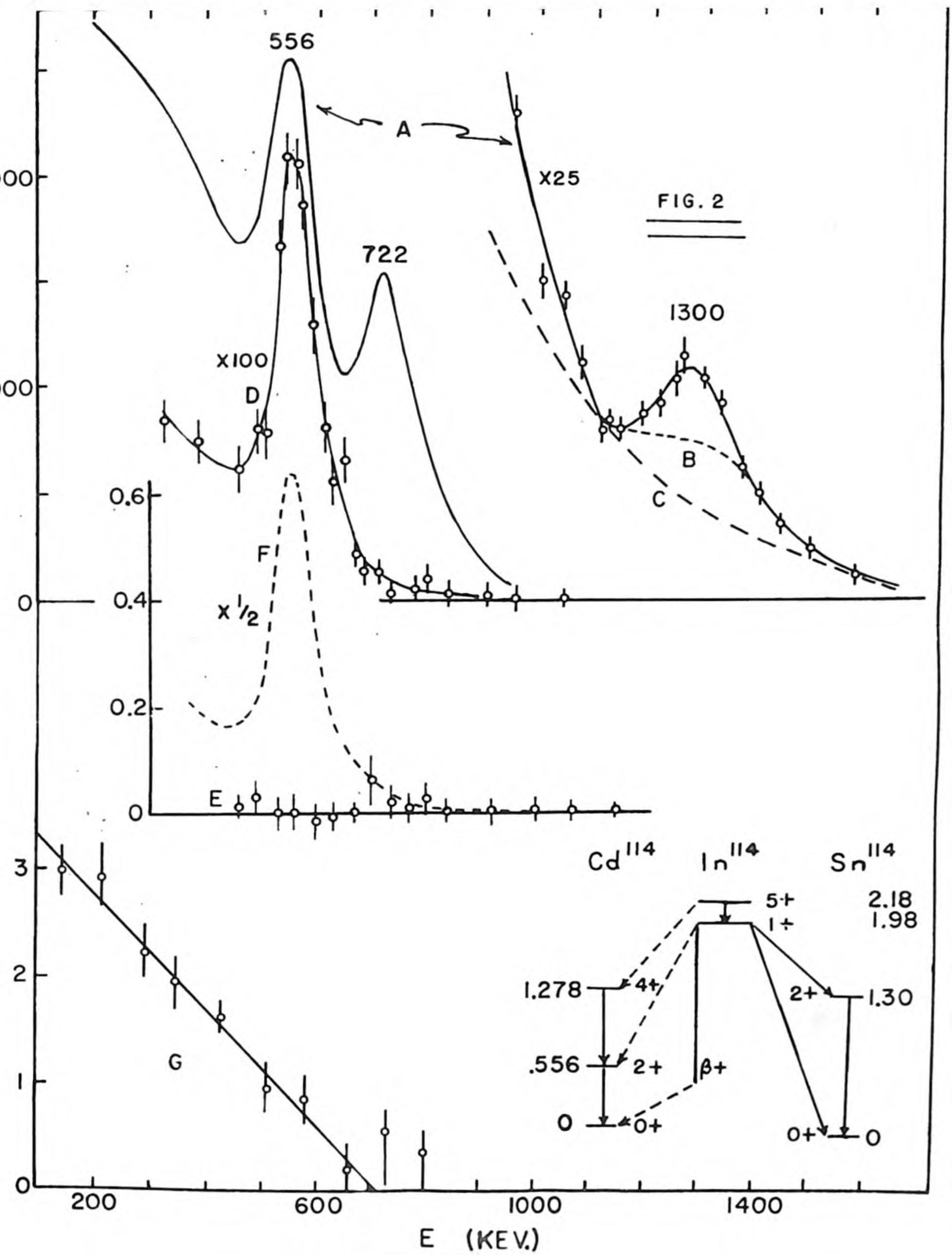


FIG. I

IN^{114} RESULTS


556
A
X25
FIG. 2
722
1300
X100
D
B
C
F
X 1/2
E
G
COUNTS / MINUTE
2000
1000
0
0.6
0.4
0.2
0
$\sqrt{N(E)/GW^2}$ X10^-4
3
2
1
0
Cd^114
In^114
Sn^114
5+
1+
2.18
1.98
1.278
4+
2+
1.30
.556
2+
β+
0
0+
0+
0
200
600
1000
1400
E (KEV.)

PART B

A STUDY OF MAGNETIC FIELD STABILIZATION

I. Introduction

The high resolution of the Siegbahn-type beta-ray spectrometer (defined as $\frac{\Delta p}{p}$ where p is the momentum and Δp is the full width of the peak at half maximum) cannot be fully utilized in making energy determinations, unless the magnetic field can be measured very accurately. The best resolution obtained with the present machine is 0.2%, and the true centre of a well defined electron peak can be located within a tenth of the half-width. Therefore an accuracy of 2 parts in 10,000 may be expected in the energy determination. The field measurement and control must be at least this accurate to obtain this precision.

A project, which was designed to overcome this difficulty of measuring the magnetic field, was begun in 1954 by Raymond Koenig (15). After a rather exhaustive survey of the literature, it was decided that the A.C. null method developed by A. Hedgran would be most promising since it could be readily extended to permit automatic stabilization of the field. Although a detailed account of his work is given in his M.Sc. thesis, it is necessary to present a brief outline of the method and equipment which he used in order to clarify the state of the project when this work was begun.

Two flat search coils, one in the spectrometer field H_1, and the other in the reference field H_2, provided by an iron-free pair of Helmholtz coils, are rotated with fixed angular velocity about a common axis. Both H_1 and H_2 are parallel and at right angles to the axis of rotation. The relative orientation of the search coils is such that the voltages which they produce are π radians out of phase. The two fields are balanced when H_2 is so adjusted that the detector shows the minimum, i.e., $H_1 = \frac{A_2}{A_1} H_2$ where A_1 and A_2 are the effective areas of the coils. Since H_1 is directly proportional to H_2 , it is also strictly proportional to the current in the Helmholtz coils.

The general mechanical layout of the apparatus is described in Koenig's Master's thesis (15). Changes in detail, which were later found necessary, will be discussed in another section.

Under optimum working conditions, Koenig had been able to match the two search coil signals to within 1 part in 30,000 and thus to determine the magnetic field to 0.01%. However, the long term stability was such that the measurements were not reproducible to better than one part in a thousand.

The lack of reproducibility was in part caused by the effect of stray fields in the room on the reference field. Since in his arrangement the reference field was small at low spectrometer field settings, the effect of these stray fields was sometimes very serious. It was felt that these effects could be largely eliminated if the current for the reference coils was always maintained at a large value. This required the construction of a separate stabilized supply for the Helmholtz coil. Moreover, it was felt desirable to adapt Koenig's field-measuring device so that it could be used to control the Siegbahn magnet current automatically from the reference field.

II. Design and Construction of Equipment

(a) General Layout A block diagram of the general layout is shown in Fig. 3. In this equipment the Siegbahn field is compared with the known reference field produced by a pair of Helmholtz coils. The power supply and current control circuits for this field are shown in the upper left hand corner of the figure. The magnitude of this field is proportional to the voltage developed across the standard resistor R_{60} as determined by the potentiometer. The reference field is compared with the magnet field by means of the search coils HSC and SSC which are mechanically coupled 180° out of phase and rotate at 25 cycles per sec. The range selector network (shown in detail) provides a means of multiplying the reference signal by factors of 0.2, 0.5, 1.0, or 2 before the comparison is made. The difference signal is fed through a tuned amplifier (15) to the phase sensitive detector. The output of this detector is amplified by a one stage D.C. amplifier and made to control the current through a bank of 807 tubes in series with the magnet supply. The resistance in series with the magnet is the control chain of the original D.C. amplifier current control built by Waterman (16). It is now simply used as a load in series with the magnet. The reference voltage for the phase sensitive detector is obtained from the output of the HSC coil through a suitable amplifier.

The new sections of this circuit will be described in detail.

(b) Helmholtz Current Supply It was required to build a very stable supply for the reference Helmholtz coils. These possess an A.C. impedance of 4100 ohms at 60 cycles per second, a D.C. resistance of 400 ohms and an inductance of 10.4 henries.

The supply was to be continuously adjustable from 100 ma. to 600 ma. This was achieved by means of the circuit consisting of R_{60} to R_{64}, in Fig. 6. The 5k helipot, R_{61}, has 15 turns which permits the changing of the current by 0.13% steps/div. to 0.05%/div., while the 10k helipot, R_{63}, with 10 turns allows careful scanning by permitting the current to be changed by 0.01%/div. to 0.003%/div.

The error signal from the 1.0189 volt standard cell is fed into the Brown Converter (Fig. 4) which compares it to ground across the two 680k ohm resistors R_{17} and R_{18}. If the negative terminal of the standard cell is not at ground potential, a signal is fed onto the grids of the 12AX7 (T_6 Fig. 4). The 3-stage push-pull amplifiers supplies a square wave output to the phase sensitive detector. The error signal from this amplifier, which has a gain of 6,000, can alter the phase sensitive detector potential (Fig. 5) by plus or minus 22 volts. The phase sensitive detector is anchored at -225 volts so that its output is coupled to the grid of the 12SH7 (T_{16} in Fig. 6) which in turn, drives the series control tubes of the main power supply. The negative supply is necessary since the plate of the 12SH7 (T_{16}) must go from -50 volts to +275 volts in order to supply the required variation in the output current.

It was necessary to supply three feedback networks to prevent hunting i.e. (i) the D.C. feedback through the chopper amplifier, (ii) the A.C. feedback through a two stage triode amplifier (overall gain of 72,000), (iii) direct condenser coupling from the output to the grid of the 12SH7 (T_{16}).

As a safeguard for the rectifiers the supply contains a relay switch in the high voltage line which is activated through a one minute delay tube. This allows the heaters of the mercury rectifiers to heat for one minute before the high voltage is impressed upon them. This of course protects the cathodes from positive ion bombardment.

When completed, the circuit was found to have a stabilization ratio of 150,000, i.e. when the voltage fed to the 6AS7 series control tubes was changed by 120 volts, the voltage developed across the load changed only by 8 mv.

The measured ripple, peak to peak, is less than 1 part in 25,000.

The total gain of the D.C. feedback circuit was measured at 312,000 and this would indicate a stability of 1 part in 312,000. This stability, however, would require careful control of the temperature of each critical component, which would be quite difficult to do. Tests revealed a satisfactory long term stability (90 min.) of better than 1 part in 20,000 and a short term stability (4 min.) of 1 part in 75,000.

Very few circuits of this type work successfully the first time. Once the circuit is made to control at low gain, one should work slowly toward higher gain in the feedback loop. Hence the desired result is obtained by making the changes required to prevent oscillations and hunting as the gain is increased. i.e. In a circuit of this nature, the gain must fall off no faster than 12.5 db. per octave and no slower than 6 db. per octave or the circuit will hunt. The small power supply for this electronics is of conventional design and is shown in Fig. 8.

(c) <u>Range Selector</u> Since the current for the reference field can only be changed from 100 ma. to about 500 ma., it is necessary to have a range selector for measuring fields which range from 10 to 400 gauss (i.e. Hr values from 500 to 20,000 gauss-cm.). The resistance values in the range selector are designed to give overlapping ranges as follows: Range 1, 550 Hr to 2830 Hr, Range 2, 1630 Hr to 11650 Hr, Range 3, 5550 Hr to 23400 Hr, Range 4, 6100 Hr to the top. This corresponds to a range of from 26 kev. to over 8 Mev.

(d) Magnet Control Circuit The main power supply is of conventional design and is described in detail by H. H. Waterman (16). The only change is the substitution of the automatic controlling circuit for the former D.C. amplifier. In this new circuit, the two signals from the search coils are mixed in the range selector circuit described above. The difference signal produced, is amplified by a sharply tuned 25 cycle amplifier (15). The maximum output signal from this circuit is 5 volts peak to peak and this is not large enough to drive the phase sensitive detector. Therefore one stage of triode amplification was introduced. The signal is then divided in a conventional phase splitter, providing the input to the phase sensitive detector. This signal is about 15 volts peak to peak and appears to be adequate. This circuit is shown in detail in Fig. 7.

The grid signals for the phase sensitive detector is provided in the same manner, from the output of the Helmholtz reference coil. This signal must always be larger than any signal from the tuned amplifier or the phase sensitive detector loses its sense of direction. The output signal from the tuned amplifier can be adjusted by a gain control following the amplifier stages.

The output of the phase sensitive detector controls the grid of a 12SH7 (T_{23}), which constitutes a single stage D. C. amplifier (Figs. 3 and 4) This amplifier drives the series control tubes of the magnet supply.

(e) Compensation for the Earth's Field. The earth's field at the reference coils is eliminated by passing current through two Helmholtz coils placed in such a position that their axes are perpendicular.

A special power supply was constructed to provide the current for these coils, and it, together with the coil load, is shown in Fig. 11. The supply is of simple design and does not require a detailed discussion. It provides 60 ma. at 53 volts stabilized to about 1%.

The earth's field is completely eliminated by monitoring the signal from the reference search coil only, when all other supplies are turned off. The current in the earth's compensating coils is adjusted until no signal appears at the output of the tuned amplifiers. This condition exists when the current in the vertical compensating coils is 50 ma. and the current in the horizontal compensating coils is 17 ma.

(f) Mechanical Alterations. It has been difficult to obtain a satisfactory system of brushes to take the signals from the rotating shaft. The first brushes used were found to be too noisy. A type of carbon brush was devised that had a satisfactorily low noise level, but its contact resistance varied with pressure. Since this made the effective internal resistance of the search coils pressure-dependent, the magnitude of their output signal depended on the pressure on the brush. The brush also introduced an appreciable load on the small constant speed motor.

The type of brushes finally adopted consists of inconel X springs driving brass pulleys in individual mountings. The pointed monel shafts of the brass pulleys project into mercury pools from which the signals are taken. This arrangement is found to be completely satisfactory. For stable operation, these brushes must be kept clean.

A great deal of trouble was experienced in obtaining a spring of non-magnetic material which would not break down under the continuous operation imposed. Both phosphor bronze and beryllium copper tended to work-harden or to wear, either of which conditions resulted in breakage within a few hours. Finally, it was found that inconel X wire of diameter 0.025 inches, wound with negative tension in a helix of diameter 0.205 inches, was satisfactory. The free ends of the spring are coupled by reducing the diameter of one end so that it can be threaded inside the other, since hooks invariably wear rapidly.

The reference Helmholtz coils used by Koenig were wound by an outside manufacturer and were not truly cylindrical. Therefore it was impossible to mount them on a common axis with the vertical earth's field compensating coils. Moreover, the mounting was such that it was very difficult to align them with the stray field of the Siegbahn magnet which is proportional to the field in the gap of the magnet. If these three fields are not properly aligned, a horizontal field component is created at the reference search coil position, which is a function of the Siegbahn magnet field. In the old arrangement, this troublesome horizontal component was large enough to overload the tuned amplifier. To remedy this situation, new reference coils were wound in our shop on a properly machined spool.

The coils align automatically with the vertical earth's compensating field coils and the complete unit can be rotated to bring it into line with the stray field from the magnet. The horizontal component of the stray Siegbahn field is not completely eliminated at present, but it has been reduced to such an extent that the circuit operates without overloading over the complete range. It should be pointed out that any horizontal component which can be tolerated by the amplifier is much too small to make a significant change in the total emf generated by the Helmholtz search coil.

III. A Study of Performance

In testing the stability of this equipment, one would like to make a direct measurement of the field in the spectrometer gap as a function of time. This might be done crudely with a flip-coil to an accuracy of about one part in a thousand, but such a method would not be sensitive enough to show the time-variations expected with this equipment. It was therefore necessary to study the field stability indirectly through tests on the constancy of the magnet current or on the reproducibility of an electron line position. These tests will be discussed in turn.

(a) Current Stability. The current through the spectrometer coils was monitored by recording the time variation in the potential drop across a resistor network in series with the magnet. This method is open to the objection that any heating in the resistance network may cause apparent drifts for a short time after a new current level was established. Such drifts were observed but were not large enough to be troublesome.

The potential drop was monitored with a Model G-10 Varian Recorder in series with a 45 volt B battery. This instrument has a full-scale sensitivity of 100 mv., so that when the potential drop across the resistor network was adjusted to 45 volts the instrument would indicate a full-scale change for a current change of about two parts in 1000. Stability curves over the complete range of the instrument were obtained and replicas of three of these are shown in Fig. 9. Curve (A) represents the stability near the top of the magnet field range. The abrupt shift in level corresponds to a manually-produced field change of three parts in 10,000. Obviously, the controlling circuit has a stability of better than 0.01%. This same curve, continued for twenty minutes, indicated a stability of 0.012%. Curve (B) indicates the stability at about the energy of the Co^{60} calibration line. A twenty-minute test here revealed a stability of 0.01%.

The poorest stability observed is represented in Curve (C) and was obtained by monitoring the Siegbahn magnet current at the weakest field possible, i.e., Hr = 26 gauss-cm. This curve represents a stability of 0.02%.

If the brushes were allowed to get dirty, it was impossible to obtain stabilities of this order.

(b) Reproducibility of Electron Lines. Many tests were made using the conversion electrons produced in foils by the 1.3 Mev Co^{60} and the 0.645 Mev Os^{185} radiations.

The results of a series of measurements made on the electron peak produced by the 0.645 Mev radiation converted in a gold foil are presented in Table II and one of these peaks is shown in Fig. 10.

TABLE II

Date of Observation	Peak Position Volts x 10^5		Comment
Aug. 4		63882	
Aug. 7		63908	
Aug. 7		63978	
Aug. 7	63779)	63915	detector out 0.5 cm.
Aug. 7	64050)		detector in 0.5 cm.
Aug. 8		63895	
Aug. 8		63900	
Aug. 9		63900	

Mean value = 63911

Standard Deviation of a single observation 32 or 0.05%.

Standard Deviation of mean value 12 or 0.02%.

For purposes of analysis the two readings of August 7, with the detector moved from the normal position were averaged. The reproducibility of a single peak position seems to be of the order of 0.05%, but it should be pointed out that most of this uncertainty is due to statistical errors in counting. If a stronger source of activity had been available, a more exacting test could have been made.

The reproducibility of the cobalt peaks was somewhat better, but the data available were not so extensive so that this apparent improvement is probably illusory.

(c) Discussion. The tests described in sections (a) and (b) above really measure two different things. The first, which measures only the current stability, indicates that the field is stable to about 0.01%. The latter, which measures the overall performance of the instrument on a peak of such strength that individual points could be recorded with a statistical error of 3% in a reasonable time, gave a stability of 0.05% (although most of this error was contributed by one measurement). With stronger peaks it should be possible to determine their positions more accurately, and perhaps approach the limit of 0.01% indicated by the current stability tests.

IV. Summary

The device described in the above thesis has been shown to be sensitive to field changes of less than 0.003%. The magnetic field stability always seems to be better than 0.02%, and on some ranges better than 0.01%.

It has been demonstrated that for peaks of moderate height, their position can be reproduced to better than 0.05% and it is believed that a limit of about 0.01% could be obtained in very favourable cases. There has not been time to prove that the potentiometer readings are accurately proportional to the electron momentum, but there is no reason to believe that this will not be so.

A similar field-measuring device reported by Hedgran (17) is claimed to be sensitive to one part in 30,000 and able to reproduce line positions to 0.03%. Our equipment appears to give comparable results.

The new device makes possible an improvement by a factor of 5 in the accuracy with which the field in the gap can be measured. It also eliminates laborious flip-coil measurements and makes it possible, in the future, to set the instrument up for automatic scanning.

This improvement has been made at the expense of simplicity and will probably demand more care in upkeep than the previous stabilizer and field-measuring apparatus.

Fig. 12 (a) and (b) are two photographs of the finished equipment.

CIRCUIT COMPONENTS

Capasitors in m.f.'s

C_1 - C_2 - 10

C_3 - 0.5

C_4 - 0.02

C_5 - C_6 - 0.002

C_7 - C_8 - 0.05

C_9 - C_{10} - 0.05

C_{11} - 30

C_{12} - C_{13} - 0.05

C_{14} - 30

C_{15} - C_{16} - C_{17} - 1

C_{18} - 0.05

C_{19} - 10

C_{20} - 30

C_{21} - 0.05

C_{22} - 10

C_{23} - 0.05

C_{24} - 30

C_{25} - C_{26} - C_{27} - 10

C_{28} - 0.5

C_{29} - 0.1

C_{30} - C_{31} - 0.05

C_{32} - 10

C_{33} - 16

C_{34} - C_{35} - C_{36} - C_{37} - C_{38} - C_{39} - 0.05

C_{40} - 10

C_{41} - 0.1

Chokes

L_1 - 10 - 100X

L_2 - 12 - S - 750

L_3 - 150

Resistors 1/2 watt unless otherwise specified in ohms

R_1 - R_2 - 220

R_3 - 100k

R_4 - 82k

R_5 - 120k

R_6 - 150k

R_7 - 220k

R_8 - R_9 - 250k w.w.

R_{10} - 180k

R_{11} - 150k

R_{12} - 250k w.w.

R_{13} - 100k w.w.

R_{14} - 000

R_{15} - 20k

R_{16} - 1k (pot.)

CIRCUIT COMPONENTS - Cont'd.

R_{17} - R_{18} - 680k

R_{19} - R_{21} - 1 meg.

R_{20} - 2.2k

R_{22} - R_{23} - 100k

R_{24} - R_{25} - 1 meg. (pot.)

R_{26} - 1.2k

R_{27} - R_{28} - 100k

R_{29} - R_{30} - 1 meg.

R_{31} - 470

R_{32} - R_{33} - 33k

R_{34} - 220k

R_{35} - 82k

R_{36} - R_{37} - R_{38} - R_{39} - 2.2 meg.

R_{40} - R_{41} - 100k

R_{42} - 1 meg.

R_{43} - 47k

R_{44} - 1.2k

R_{45} - 1 meg. (pot.)

R_{46} - 47k

R_{47} - 1.2k

R_{48} - 1 meg.

R_{49} - 500k

R_{50} - R_{51} - 10, (10 watts in each plate)

R_{52} - 500, (10 watts)

R_{53} - 7k, (25 watts)

R_{54} - 50, (10 watts)

R_{55} - 3k, (10 watts)

R_{56} - 5k, (10 watts)

R_{57} - 20k (pot.)

R_{58} - 500k

R_{59} - 470k

R_{60} - 107 (special)

R_{61} - 5k (helipot)

R_{62} - 1k

R_{63} - 10k (helipot)

R_{64} - 200k

R_{65} - 50k

R_{66} - 1 meg.

R_{67} - 1k

R_{68} - R_{69} - R_{70} - 20k

R_{71} - 1 meg.

R_{72} - R_{73} - R_{74} - R_{75} - 10 meg.

R_{76} - R_{77} - 22k

R_{78} - 1 meg.

R_{79} - 50k

R_{80} - 1k

R_{81} - 1 meg.

R_{82} - 20k

CIRCUIT COMPONENTS - Cont'd.

Transformers

t_1 - 275B x 60

t_2 - 167

t_3 - t_4 - 437

t_5 - special 453

Tubes

T_1 - 5Y3

T_2 - 6Y6

T_3 - T_4 - 6SL7

T_5 - 5651

T_6 - T_7 - T_8 - 12AX7

T_9 - T_{10} - 6SN7

T_{11} - 12AX7

T_{12} - 115NO 60 (delay tube)

T_{13} - 866 (4)

T_{14} - 6 X 5

T_{15} - 6AS7 (3)

T_{16} - 6SH7

T_{17} - VR - 150

T_{18} - VR - 75

T_{19} - T_{20} - T_{21} - T_{22} - 12SL7

T_{23} - 12SH7

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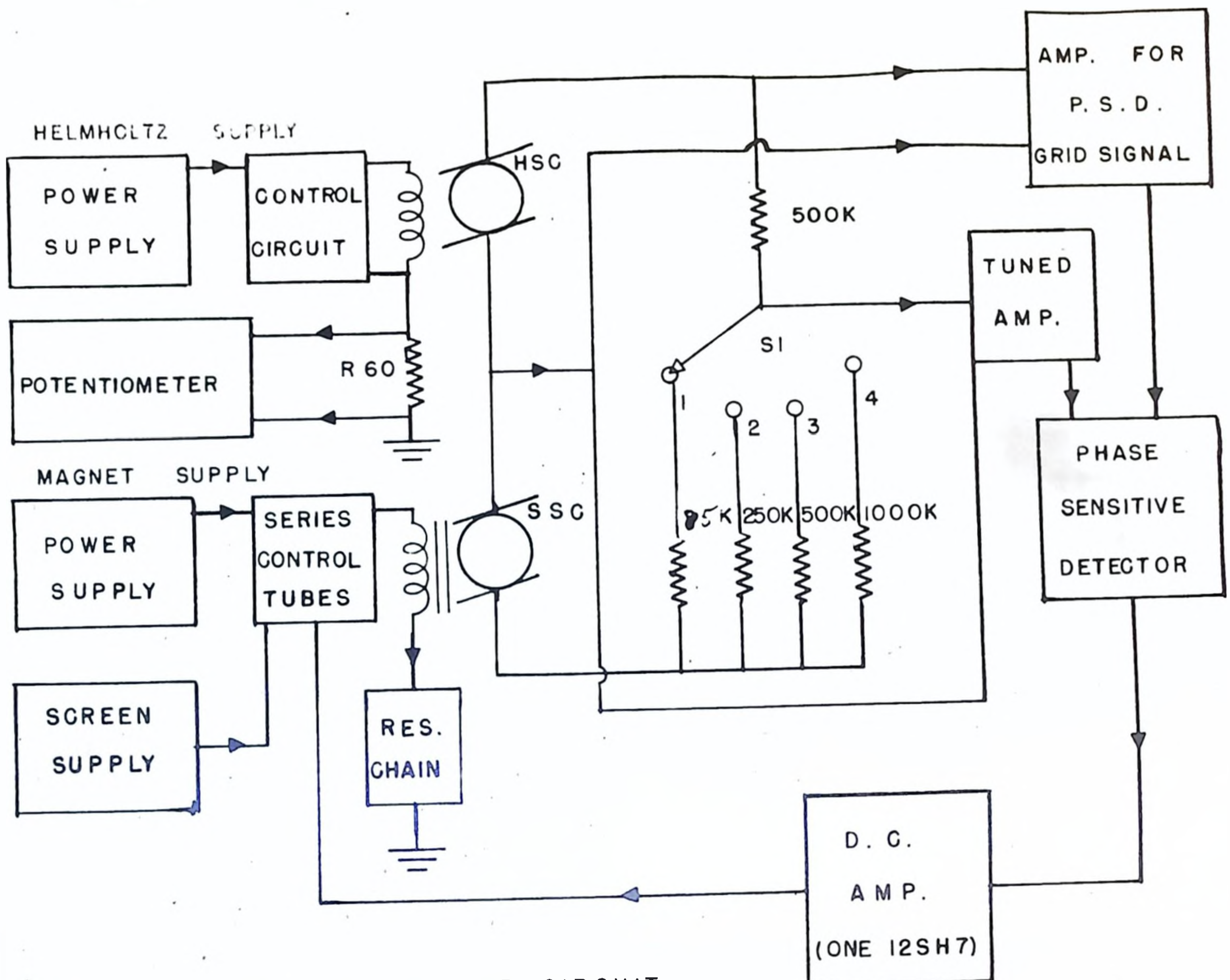


FIG.3 BLOCK DIAGRAM OF CIRCUIT

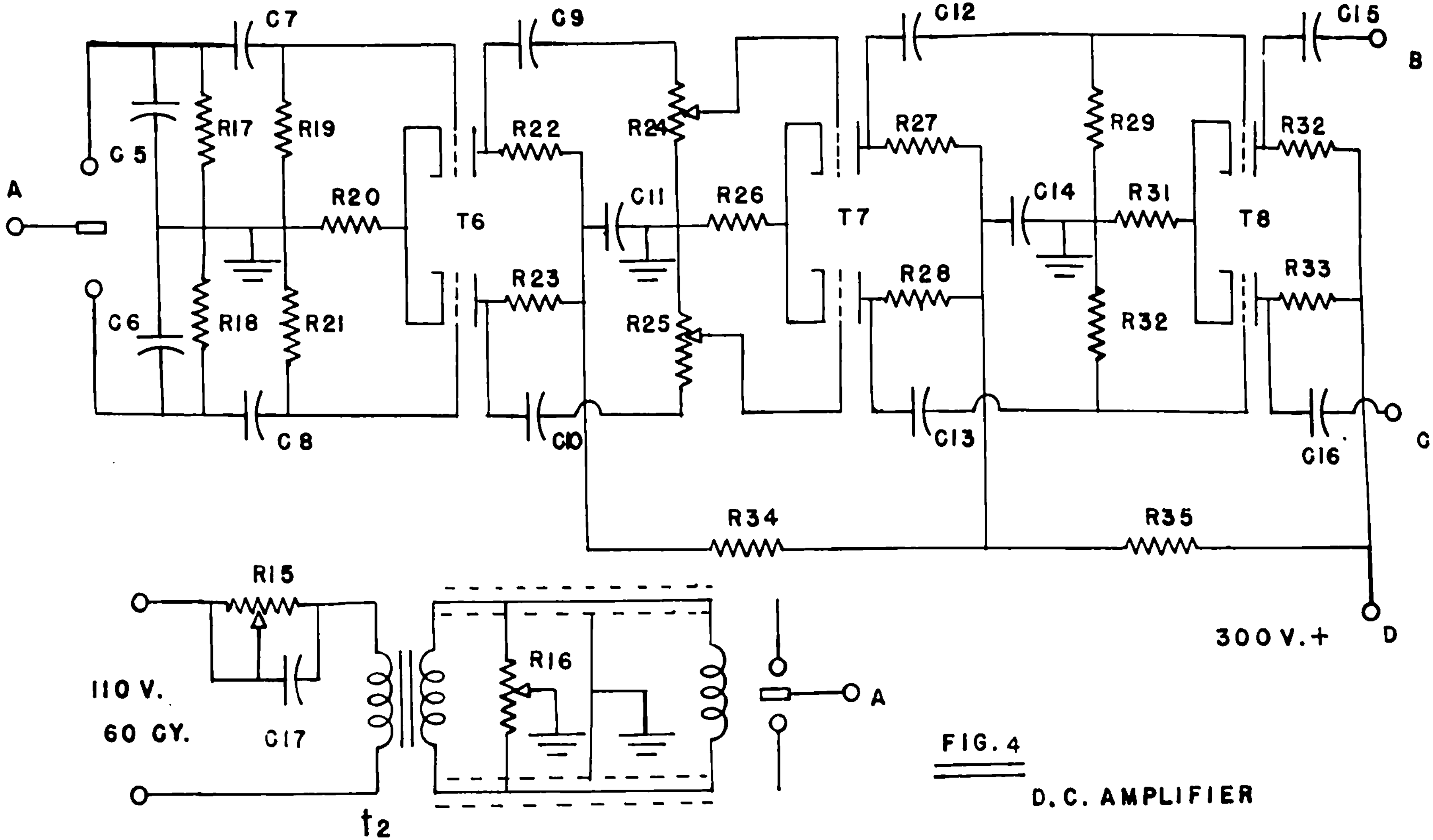


FIG. 4

D. C. AMPLIFIER

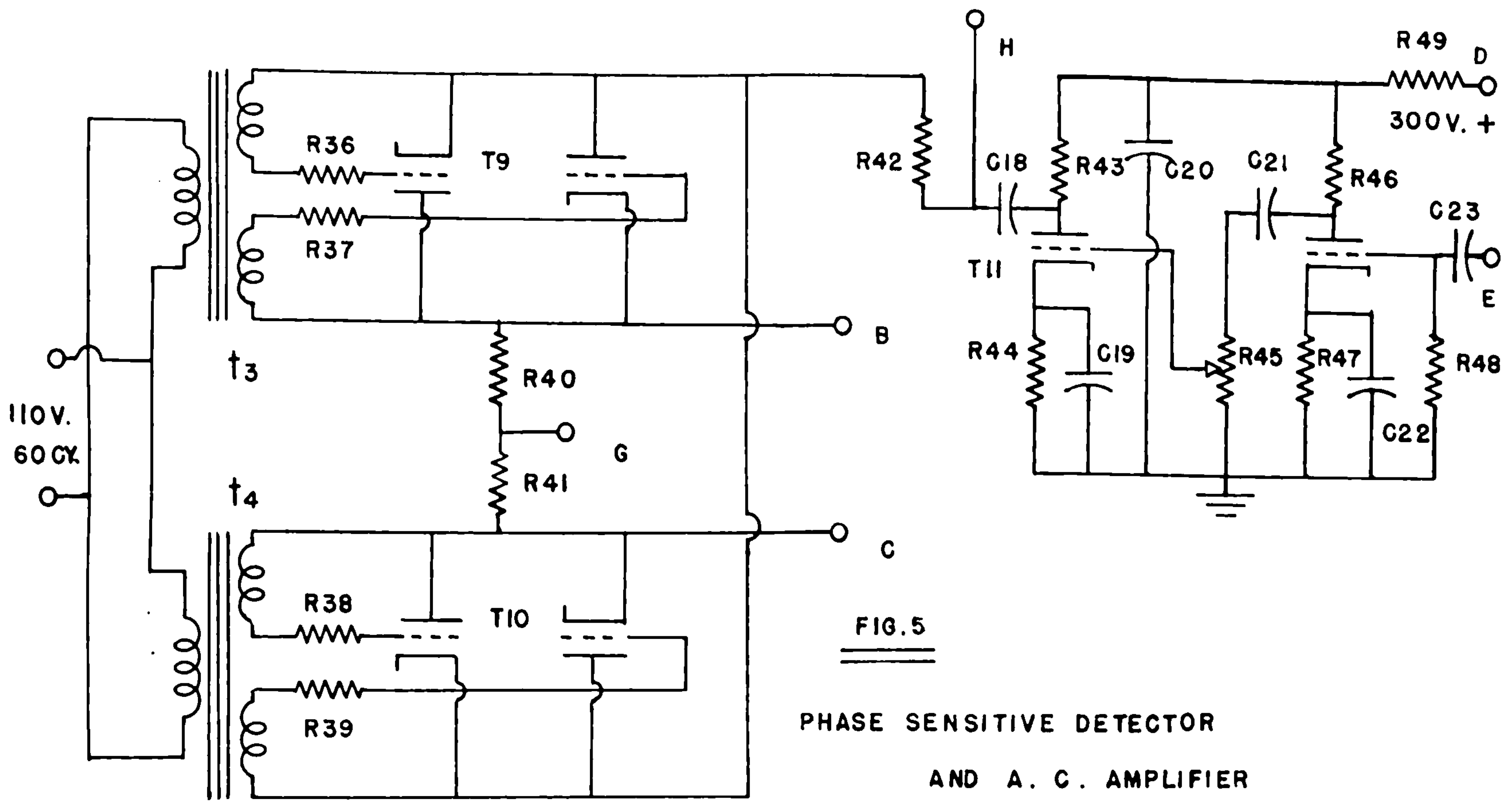
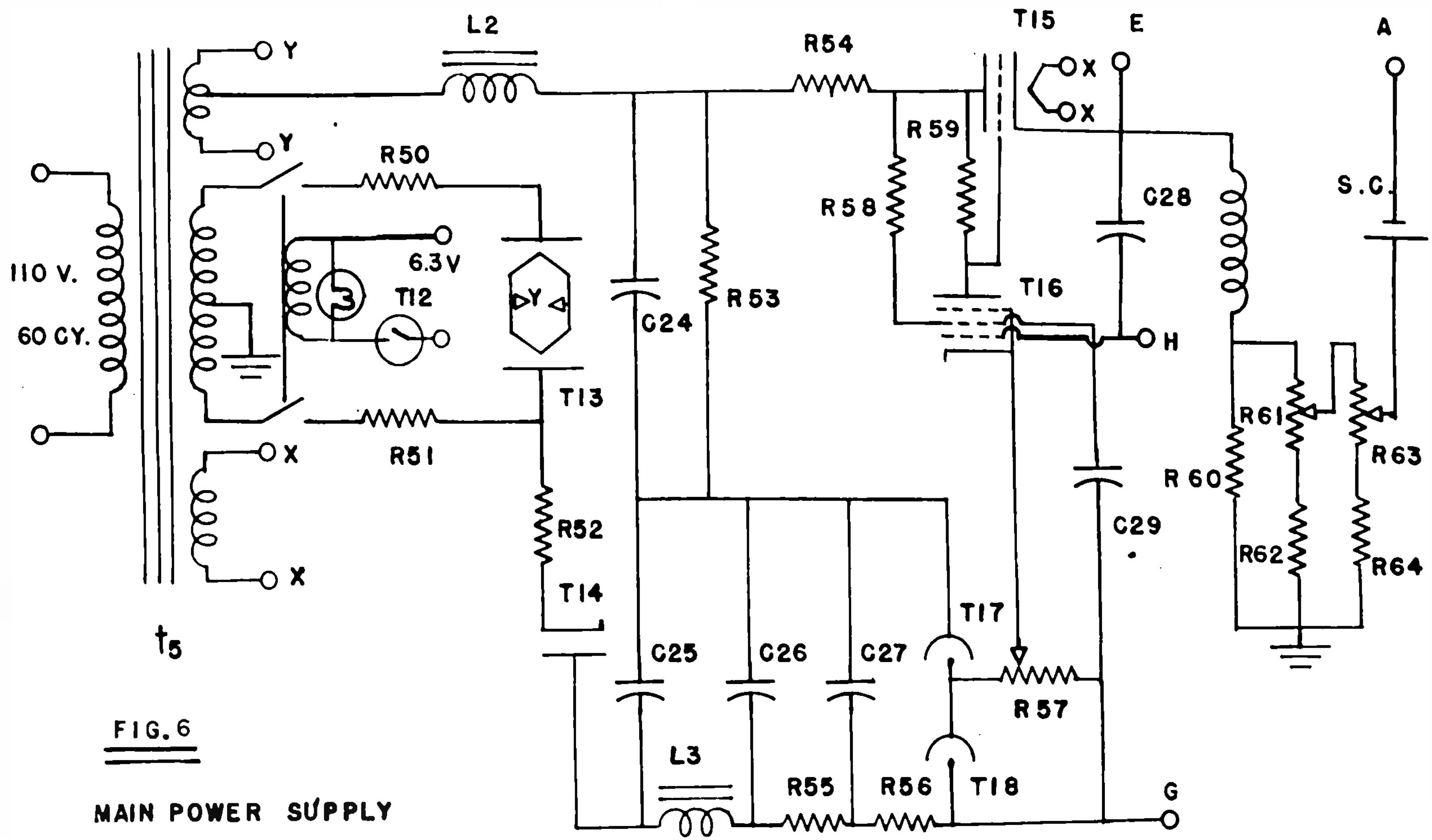


FIG. 5

PHASE SENSITIVE DETECTOR

AND A. C. AMPLIFIER



t_5

FIG. 6

MAIN POWER SUPPLY

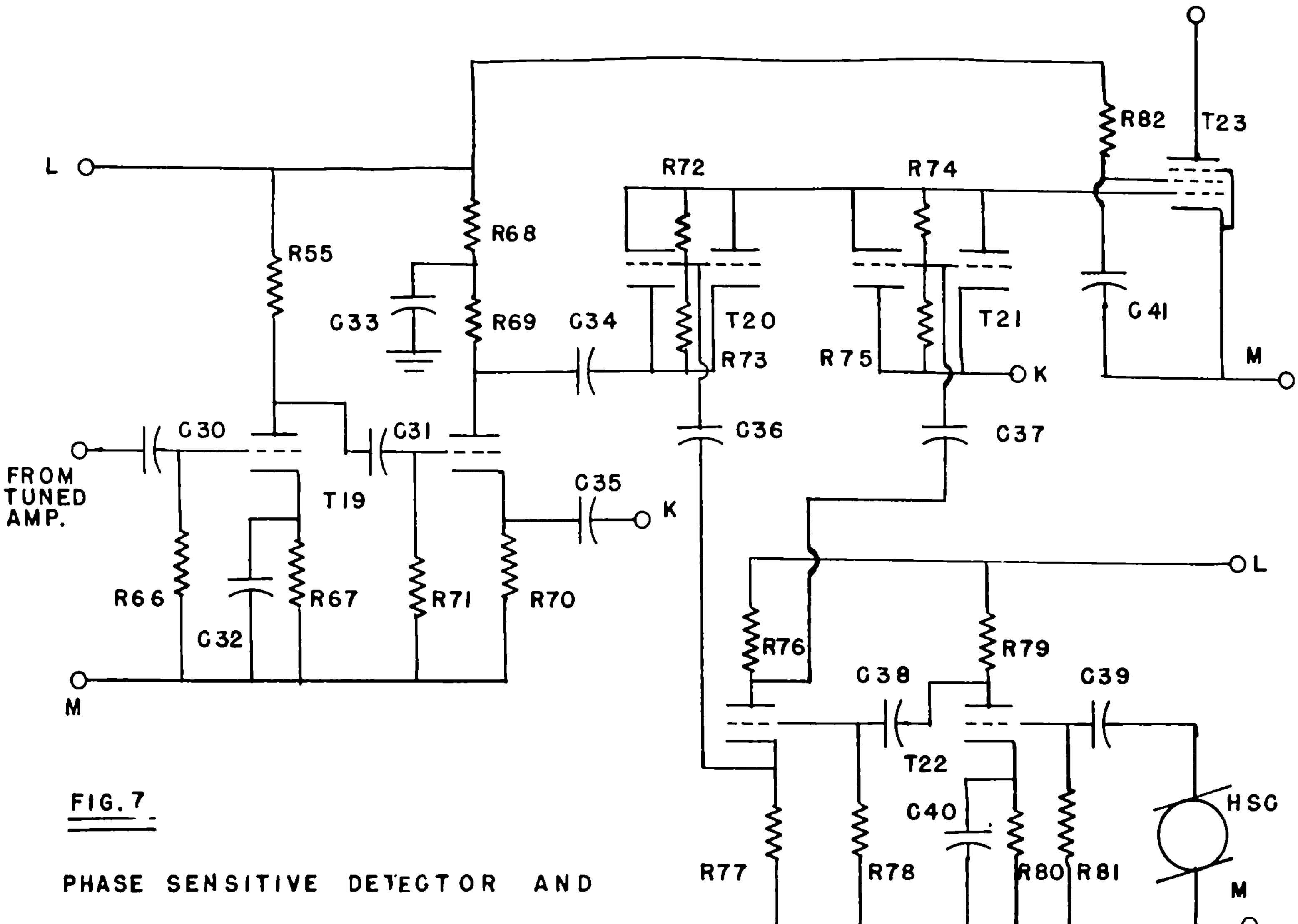


FIG. 7

PHASE SENSITIVE DETECTOR AND ITS DRIVING CIRCUITS

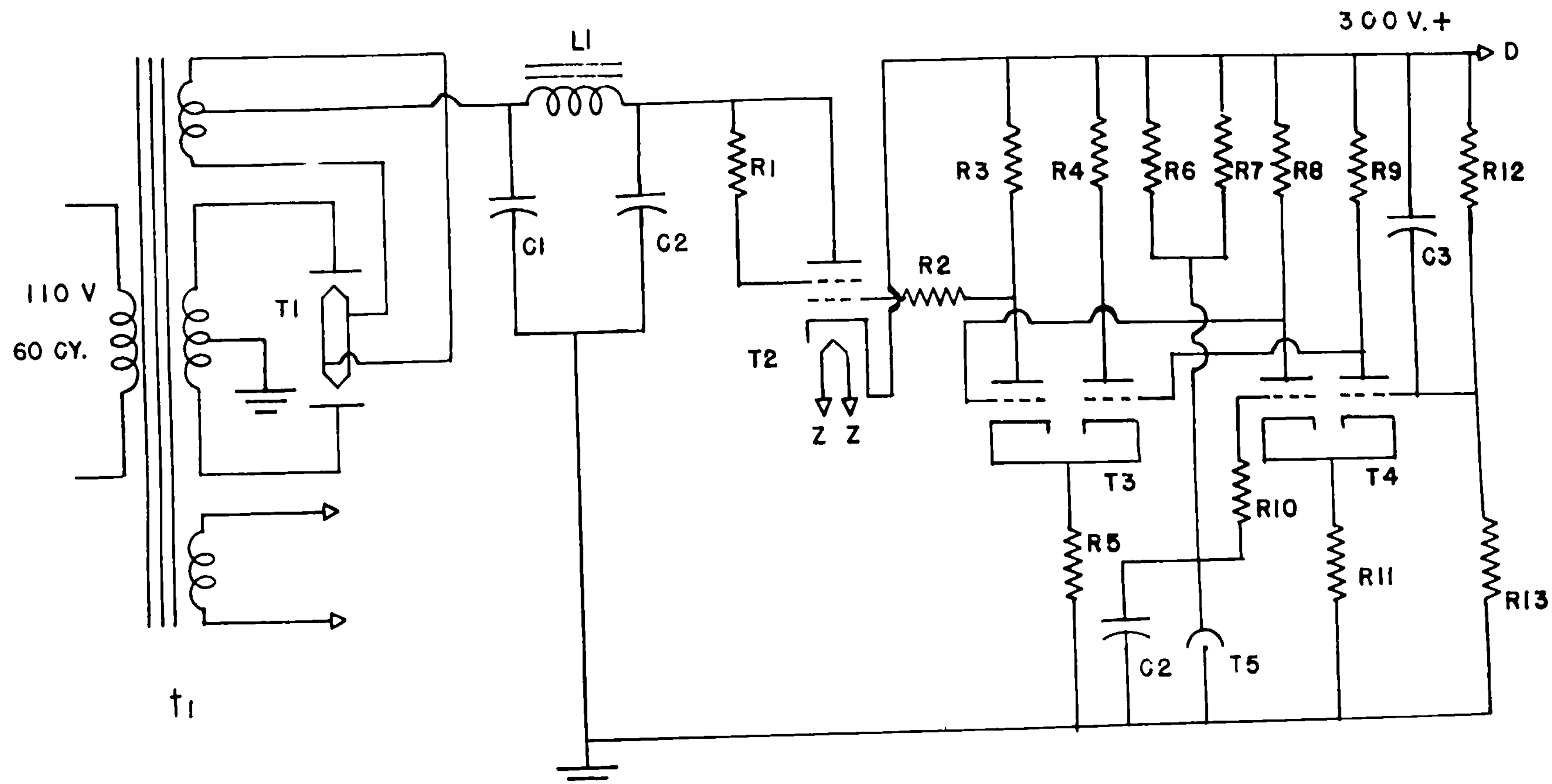


FIG. 8

POWER SUPPLY

FIG. 9 STABILITY CURVES

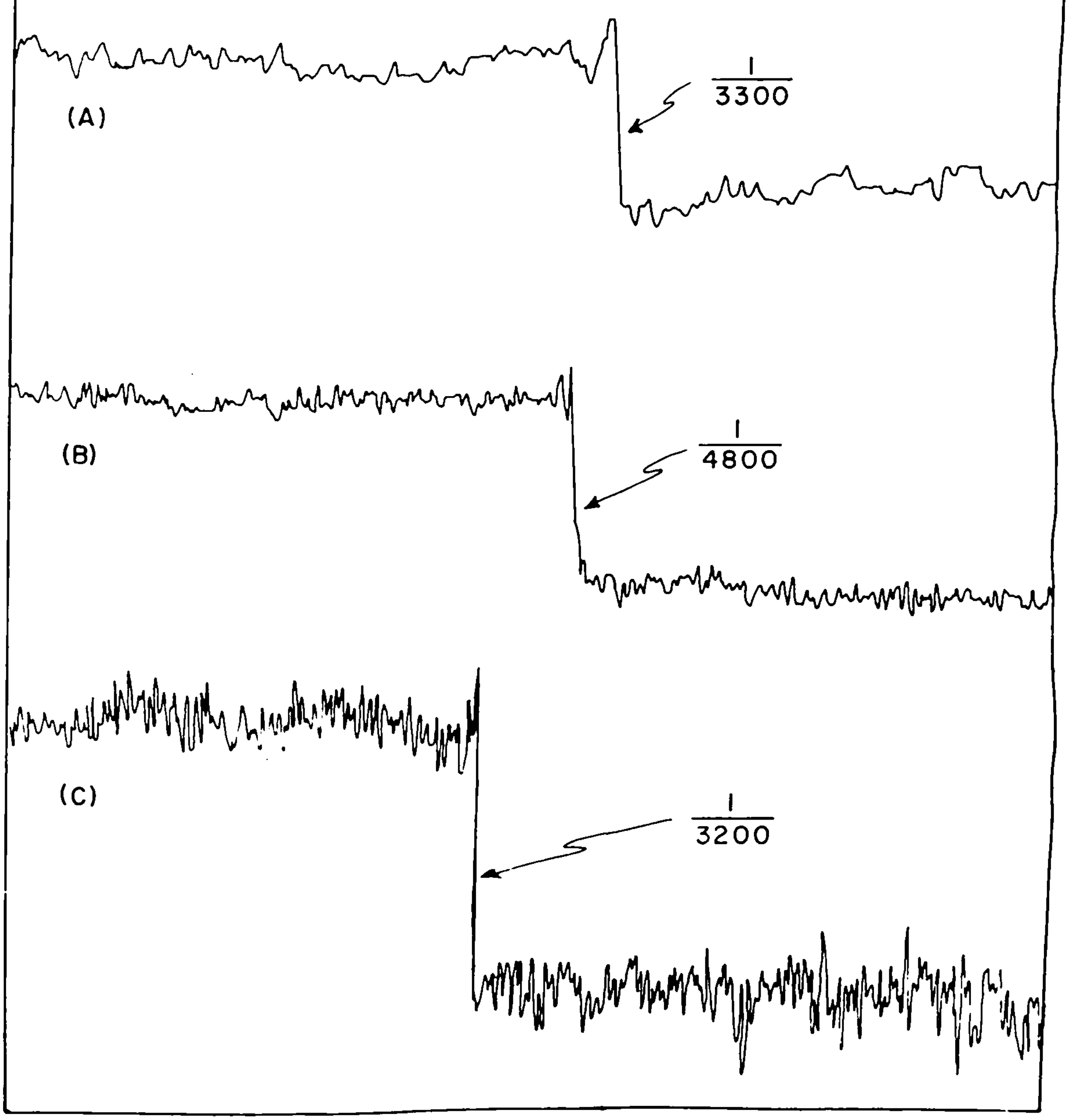
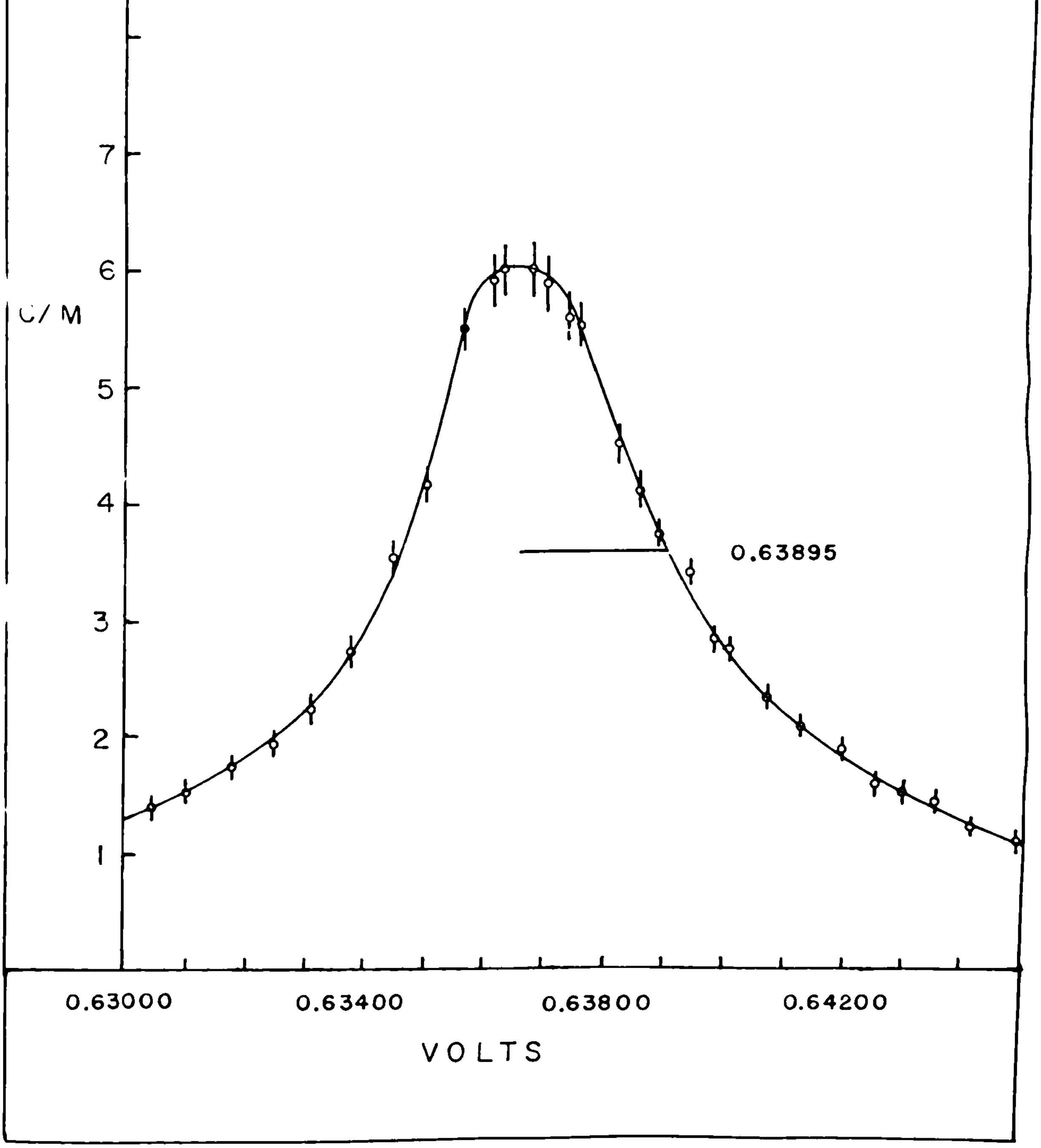


FIG. 10 OS^{185} 645 KEV. PEAK



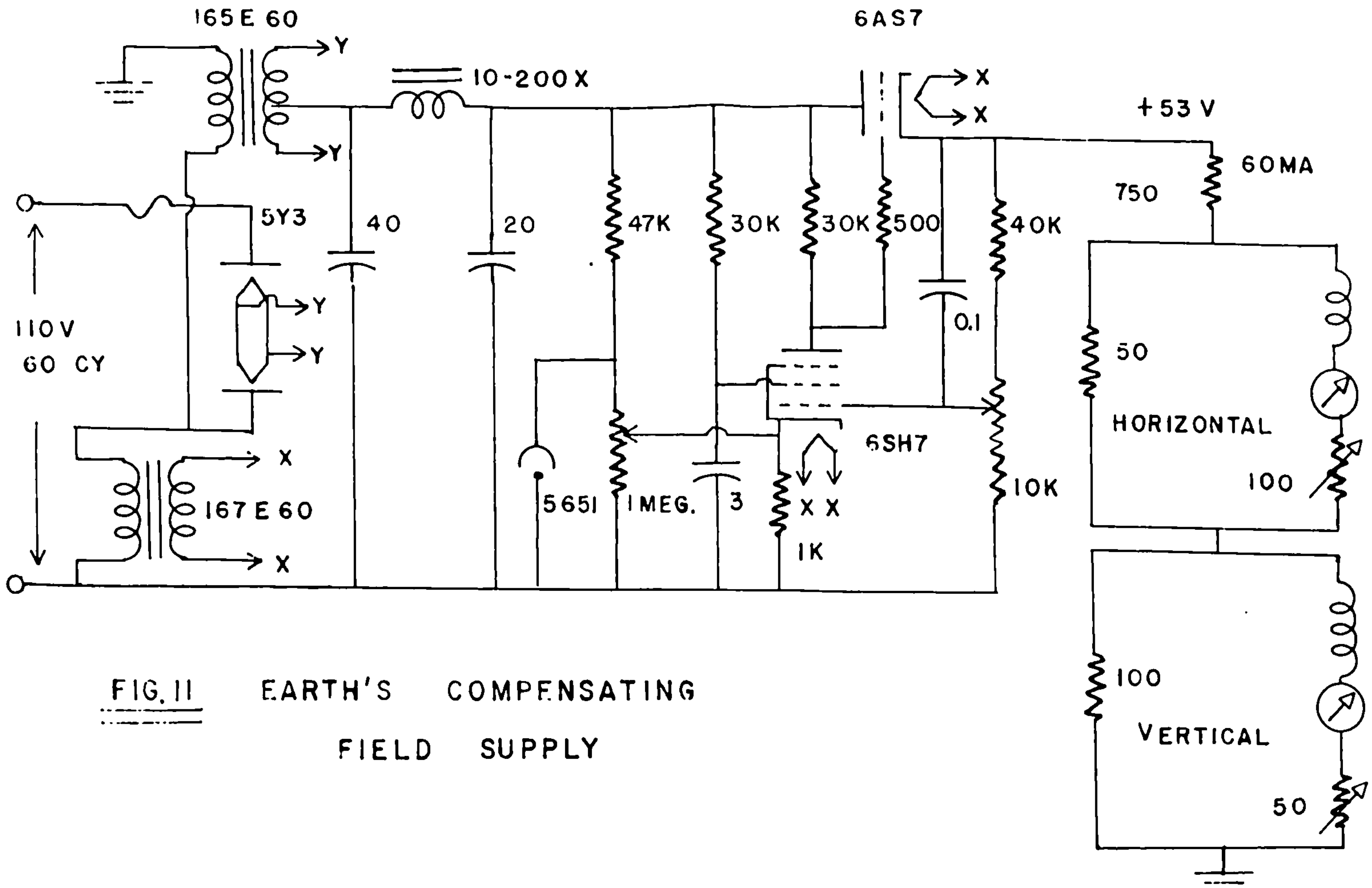


FIG. 11 EARTH'S COMPENSATING FIELD SUPPLY

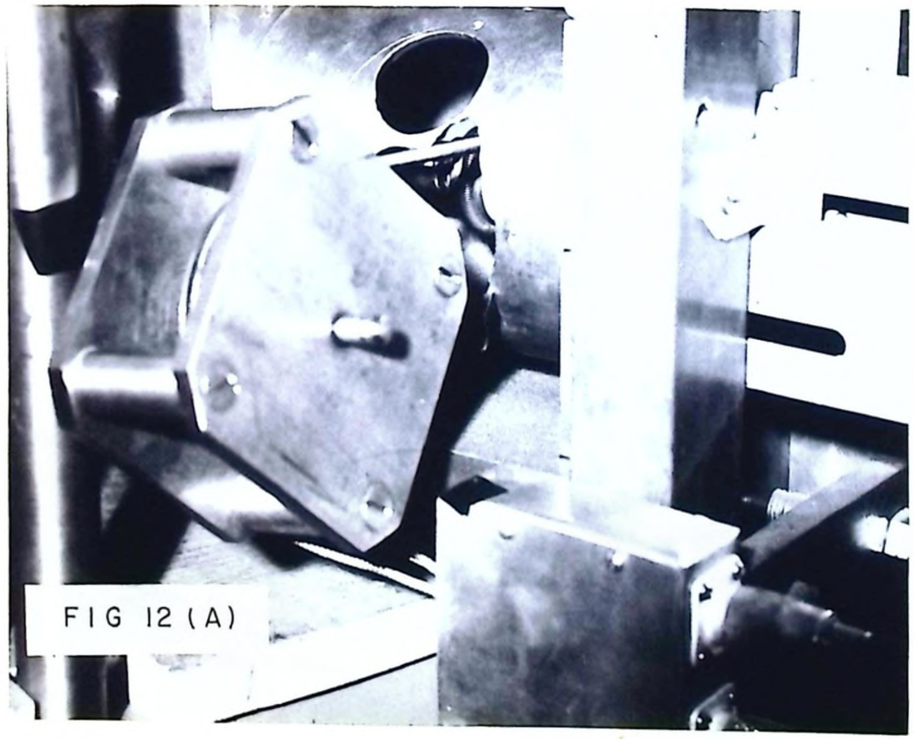


FIG 12 (A)