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ELECTRON-ELECTRON COINCIDENCE SPECTROMETER BRS-IV

John P. Unik

May 1960

ELECTRON-ELECTRON COINCIDENCE SPECTROMETER BRS-IV

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ELECTRON-ELECTRON COINCIDENCE SPECTROMETER BRS-IV

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May 1960

PURPOSE OF THIS REPORT

This report summarizes the original construction and recent modifications of the electron-electron coincidence spectrometer BRS-IV located in Building 70 of the Lawrence Radiation Laboratory.

In addition to new information on the modified spectrometer, this report also contains a large amount of material taken from two previous UCRL reports:

- 1) J. Juliano, Coincidence Nuclear Spectrometry With Applications to Europium-154 and Europium-155 (Thesis), UCRL-3733, April 1957.
- 2) J. Unik, Coincidence Measurements in Nuclear Decay Scheme Studies (Thesis), UCRL-9105, March 1960.

These reports will be referred to throughout the text as (JJ 57) and (JU 60) respectively.

ELECTRON-ELECTRON COINCIDENCE SPECTROMETER BRS-IV

I. ORIGINAL DESIGN AND MODIFICATION

A. Introduction

A nuclear decay scheme for a particular isotope can be constructed from sum relationships of the energies and intensities of the observed transitions between different nuclear states. However, ambiguities generally exist in the establishment of a unique decay scheme by this method, the number of ambiguities strongly dependent on the complexity of the decay scheme and the accuracy of the determined transition energies. By determining the coincidence relationships between various transitions, these ambiguities can generally be removed. Coincidence spectrometers using thallium-activated NaI scintillation crystals to detect the gamma rays have been widely used for this purpose. However, the use of NaI crystals as scintillation detectors is quite limited in the study of complex decay schemes because of their poor resolution ($\sim 9\%$ at 500 Kev and $\sim 14\%$ at 100 kev) and also because of the interference of the continuous background of coincidence with the Compton distribution from higher-energy gamma rays.

These bad features can be removed by using magnetic spectrometers to resolve the internal-conversion electrons of the various transitions in place of NaI crystals resolving the various gamma rays. The energy resolution of the electron spectrometers can be very much better than that of NaI, and in electron-capture decay there is no coincident continuous distribution under the electron lines. Unfortunately, with the improved features of electron-electron coincidence techniques there are a number of associated bad features. The equipment and experimental methods are very much more complex, and the coincidence counting rates are less by several orders of magnitude than for gamma-gamma ray coincidence measurements.

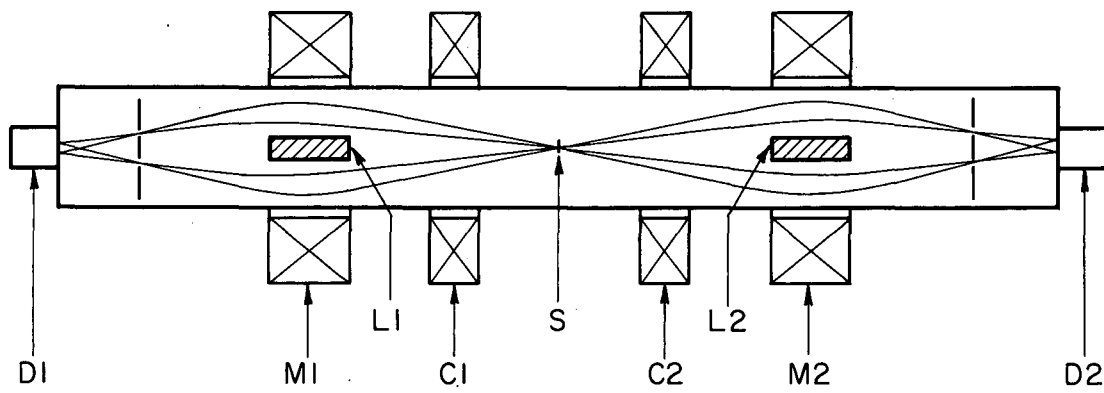
B. Original Spectrometer

Construction of the original spectrometer was started by Passell and others in 1953 and was completed by Juliano in 1957 (JJ 57). The original design used for this spectrometer was based on a β -spectro-goniometer constructed by Siegbahn in 1951.¹

The original spectrometer consisted of two collinear thin-lens beta spectrometers back to back (Fig. 1). Electrons emitted from the source S in the center of the evacuated spectrometer were focused on detectors D1 and D2 at the ends of the spectrometer by using the focusing properties of the thin-lens magnets M1 and M2. The trajectories of the electrons and hence the momentum resolution and transmission were defined by a suitably constructed baffle system. Lead plugs L1 and L2 shielded the detectors from direct radiations from the source. The entire spectrometer was constructed free of iron so that the magnet current would be directly proportional to the momentum or magnetic rigidity (H_0) of the electrons. By varying the currents in magnets M1 and M2, electrons of different energies could be focused on detectors D1 and D2. The detectors were either anthracene crystals or Livermore plastic scintillators. In order to make each half of the spectrometer magnetically independent of the other half, the compensating magnets C1 and C2 were used. Each of these compensating magnets was connected in series but with opposite magnetic polarity to the main magnet on the same side of the spectrometer. The numbers of turns of wire in the compensating magnets were chosen so that their magnetic fields would essentially cancel out the tailing magnetic fields in the other half of the spectrometer due to the main magnets. With the magnets used in this way, the two halves of the spectrometer were essentially independent of each other.

The very long electron path lengths of 100 cm from source to detectors made it necessary to eliminate the earth's magnetic field at the site of the spectrometer. Low energy electrons suffer substantial deflections by the earth's magnetic field over this length. The elimination of the earth's magnetic field was achieved by use of rectangular Hemholtz pair coils around the spectrometer.²

The spectrometer was designed to yield a 1% transmission with a resolution of 2%. However these characteristics were never achieved. The transmissions of both halves of the spectrometer were measured independently by this



10cm

MU - 19753

Fig. 1. Original electron-electron coincidence spectrometer.

investigator with a calibrated Bi²⁰⁷ source as 0.20% and 0.23%. The absolute counting rates of the 570- and 1064-keV gamma rays from the Bi²⁰⁷ source were determined with a 3x3-inch NaI crystal under known geometry and using the photo peak efficiencies given by Heath.³ The K-conversion coefficients of 0.0165 and 0.103 were used for the 570- and 1064-keV transitions respectively. These represent the average of the conversion coefficients determined by McGowan and Campbell⁴ and by Wapstra.⁵ These transmissions were also checked using Pa²³³ and Cs¹³⁷ sources.

The very low transmission of 0.002 and an associated resolution of 0.023 represents a low figure of merit for present-day beta-ray spectrometers. The low transmission is a serious limitation for coincidence work.

Let us consider the hypothetical decay scheme shown in Fig. 2. The coincidence counting rate between K internal-conversion electrons of transitions E1 and E2, assuming 100% efficient detectors, is given by

$$N(E1-E2) = N_0 T_1 T_2 X_1 X_2.$$

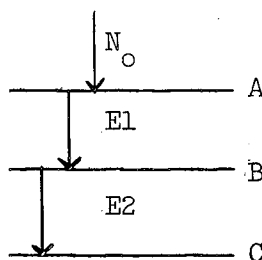


Fig. 2 Hypothetical decay scheme

N_0 represents the population per unit time of excited state A, T_1 and T_2 are the transmissions of each half of the spectrometer, and X_1 and X_2 are the K-electron internal-conversion probabilities for E1 and E2. X is simply related to the conversion coefficients by $X = \frac{\alpha_K}{1+\alpha_T}$, where α_K is the K-conversion coefficient and α_T is the total conversion coefficient. For an example assume $Z = 80$, $E_1 = E_2 = 350$ keV, and both transitions of E2 multipolarity. For this case $\alpha_K = 0.042$ and $\alpha_T = 0.068$. To obtain a "reasonable" coincidence counting rate of 10 coincidences per minute, N_0 must be $2.5 \times 10^9 \text{ min.}^{-1}$. In general

this represents a lower limit on source activity, since more active sources are required for an equivalent coincidence counting rate if excited state A is populated in only a small fraction of the total disintegrations of the parent and there are competing modes of de-excitation for excited states A and B.

Since the coincidence counting rates depend on the product of the transmissions of both halves of the spectrometer and the product of the conversion coefficients (in the limit $\alpha_T \ll 1$), the very low transmissions placed severe limitations on the radioactive isotopes that were to be studied. Only coincidences between rather intense and highly converted transitions could be successfully investigated. The beta decay of Pa²³³ was studied first (JU 60) since in addition to a number of highly converted transitions it also had a conveniently long half-life of 27 days. This investigation resolved several ambiguities between previous investigations but a detailed study of this isotope was impossible due to the very low transmissions. At this point it was found necessary to modify the spectrometer and also to build a new coincidence circuit to handle higher counting rates.

C. Modification of Electron-Electron Coincidence Spectrometer

1. Introduction

Several other laboratories have constructed similar thin-lens electron-electron coincidence spectrometers, and they have all generally found them of limited utility. This type of spectrometer has much too small a transmission to become a generally useful research tool. The Livermore laboratory has tried to circumvent the difficulty of low transmissions in both halves of the spectrometer by converting the spectrometer into an electron-gamma ray coincidence spectrometer, i.e., one half of the spectrometer has been replaced by a NaI scintillation crystal. Also attempts have been made to use the existing magnets to construct a single high transmission intermediate-image beta-ray spectrometer of the Slätis-Siegbahn type. Sergienko has modified a thin-lens electron-electron coincidence spectrometer by adding toroidal correcting magnets to each half of the spectrometer.⁶ The original spectrometer

had transmissions of 0.006 and 0.013, with associated resolutions of 0.025 and 0.04 respectively, for a 2-mm-diameter source. With the toroidal correcting magnets, a transmission of 0.02 was obtained at a resolution of 0.035. Since the coincidence counting rate depends on the square of the transmission, Sergienko's modification increased the coincidence counting rates by a factor of roughly four.

The most successful electron-electron coincidence spectrometer to date has been constructed by Gerholm.⁷ Each half of this spectrometer is a thick lens iron spectrometer with a triangular-shaped magnetic field, zero at the source and increasing roughly linearly along the axis. Theoretical calculations by Lindgren show that the effect of source width on the resolution is much smaller with a triangular magnetic field than with a uniform magnetic field.⁸

The Gerholm spectrometer has a quoted resolution of 0.013 at a transmission of 0.03 for a 2-mm-diameter source and a resolution of 0.031 at a transmission of 0.03 for a 5-mm-diameter source.⁷ However, most of the work with the spectrometer has been performed at a resolution of 0.025 and transmissions of 0.025 to 0.030 for a 2-mm source.

Since the Gerholm spectrometer has such good characteristics, it seemed worth while to examine the possibility of modifying the existing spectrometer to a spectrometer similar to that of Gerholm's. It was felt that if the same magnetic field shape could be obtained, a resolution and transmission similar to that of the Gerholm spectrometer might also be obtained.

2. Magnetic Field

The design and construction of the original electron-electron coincidence spectrometer left only a small number of variables by which the magnetic field shape could be changed. The positions of the main magnets M1 and M2 were permanently fixed, while the compensating magnets C1 and C2 could be moved 6 inches along the axis of the spectrometer. The main magnets were divided into three sections, each section containing a total of 950 turns of copper wire. Taps were provided in these sections so that either the full

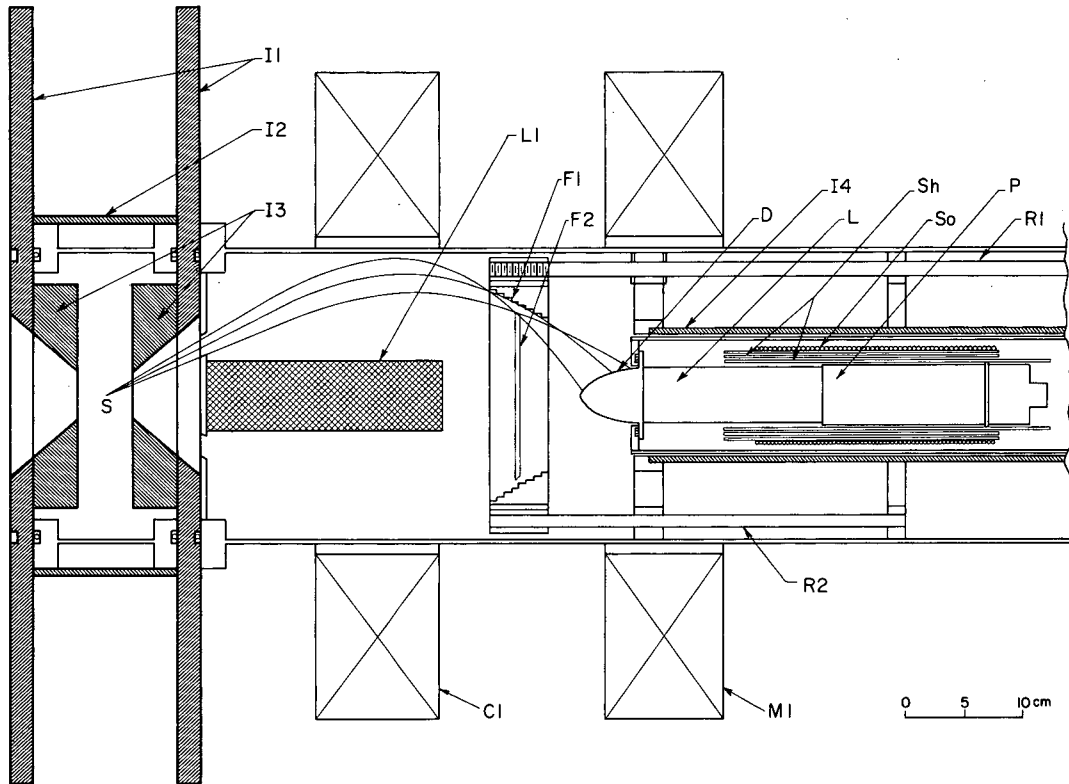
950 turns or the inner 790 turns could be used. The compensating magnets were divided into two sections each consisting of 550 turns of copper wire. Taps were placed in the coils so that 25, 50, 125, 275, or the full 550 turns could be used.

In order to obtain a "thick-lens" magnetic field the entire number of turns in the compensating magnet C1 was connected in series to the main magnet M1 with the same magnetic polarity. In order to shield the source position from magnetic fields and to make each half of the spectrometer magnetically independent, two large mild steel disks (I1, Fig. 3) 3/4-inch-thick by 26 inches in diameter, with 1-1/2-inch-thick iron steps (I3), were placed on either side of the original center section. A 1/4-inch-thick iron band (I2) was also placed around the original center section.

A number of magnetic field determinations were performed with different numbers of turns in the main magnet and various positions of the compensating magnet. With 950 turns in the two sections of the main magnet nearest to the source, a magnetic field shape (Fig. 4a) very similar to that of the Gerholm spectrometer (Fig. 4c) was obtained. Both the ordinate and the abscissa of the Gerholm magnetic field plot vs axial distance were normalized to that of Fig. 4a. The two magnetic field shapes are very similar for axial distances of less than 46 cm from the source. The magnetic field in the Gerholm spectrometer falls rapidly to zero at 46 cm in Fig. 4c owing to the presence of an iron wall. No such magnetic shielding exists in the curve of Fig. 4a, and the magnetic field for distances greater than 46 cm falls off very slowly.

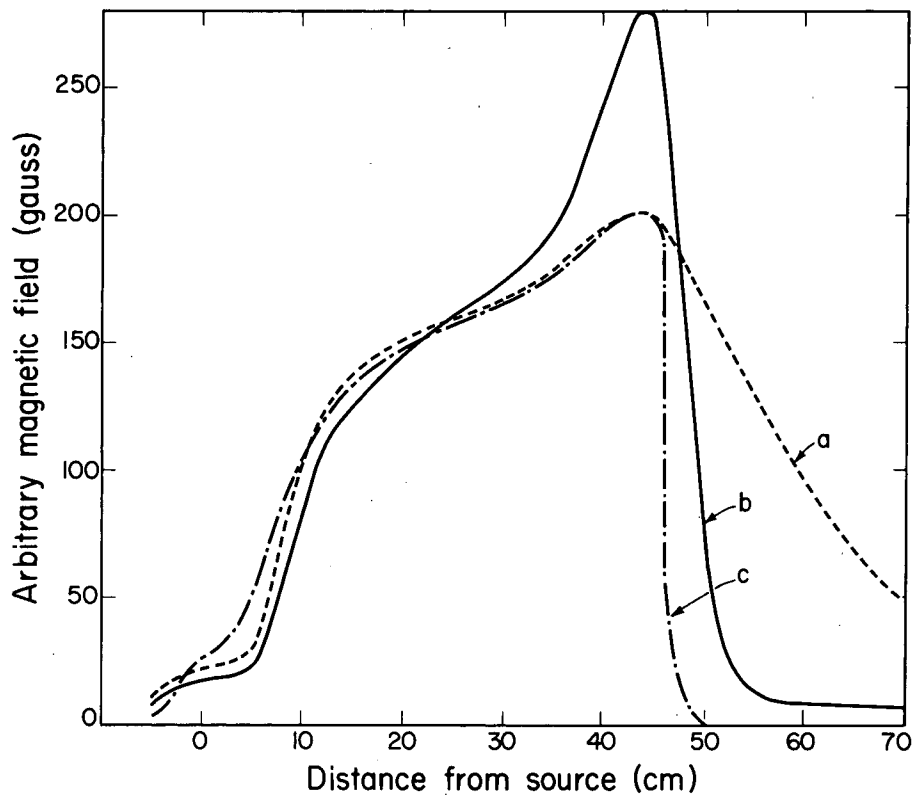
To use the spectrometer with this tailing magnetic field would require the use of long light guides to "pipe" the light output of the scintillators to a relatively low magnetic field region where a photomultiplier tube could be used. These long light guides would introduce a serious loss in light collection efficiency and would seriously hamper the use of the spectrometer. It was therefore necessary to "cut off" the magnetic field quite sharply just behind the scintillation detector. Several different configurations of iron shielding were investigated. The iron magnetic shielding to be used must satisfy the following criteria:

- a) Must cut off the magnetic field sharply.
- b) Must not appreciably change the magnetic field shape from that of the Gerholm spectrometer.



MU-19758

Fig. 3. One half of modified electron-electron coincidence spectrometer.



MU-19759

Fig. 4. Magnetic field along the axis of the spectrometer.
(a) 950 turns in two sections of main magnet - no iron cylinder.
(b) 750 turns in two sections of main magnet - with iron cylinder.
(c) magnetic field in Gerholm spectrometer (normalized).

- c) Must possess a very low remanent magnetic field.
- d) Must be fairly light in weight since the thin aluminum vacuum tank was not designed to support a heavy weight.
- e) Must not interfere with evacuating the spectrometer since the vacuum pumps are located at the extremities of the vacuum tank.

It was found that a simple mild steel cylinder with a wall thickness of 1/4-inch (I4 of Fig. 4) was the best shield for satisfying all five criteria. Other iron configurations investigated included concentric iron cylinders and a 1-inch thick iron wall with a 1/4-inch thick iron cylinder.

The introduction of this iron cylinder cut off the magnetic field rather sharply as expected, however it also altered the field distribution from 20 cm to 40 cm. Curve b of Fig. 4 shows the best approximation to the magnetic field shape of the Gerholm spectrometer that could be obtained with the inserted iron cylinder. Only 790 turns in the first two sections of the main magnet were used, instead of the previous 950 as for a in Fig. 4. Both Fig. 4a and b are for the same current passing through the magnets.

The magnetic field at the site of the photomultiplier tube was not completely eliminated by the iron shielding. To reduce the magnetic field to less than 0.1 gauss, two concentric cylindrical mu-metal shields (Sh of Fig. 3) were placed around the phototube P, and over this entire assembly was placed a solenoid magnet So. The solenoid magnet was constructed so that its magnetic field shape approximated the magnetic field inside the iron cylinder and was of opposite magnetic polarity. By use of a 6-inch light guide and the mu-metal shields, the phototube was completely isolated from magnetic flux at all field strengths below that corresponding to focusing a 730-kev electron. At higher magnet currents the solenoid was used to cancel out the magnetic field within the iron cylinder.

3. Construction of Baffle System

The trajectories and the position of ring focus of the electrons were determined by exposing Kodak No-Screen X-ray Film placed in the spectrometer to a Cs¹³⁷ source. The films were placed at various positions in the spectrometer, both parallel and perpendicular to the axis of the spectrometer. The entire baffle system was constructed on a circular brass and aluminum rack so that it could be moved in and out of the spectrometer for adjustments.

After the film exposures the trajectories of the electrons were defined by the conical aluminum outer envelope (F1, Fig. 4) and the inner defining ring (F2). The conical outer envelope was machined in steps to minimize scattering of the electrons from the aluminum.

The use of a conical outer envelope has several advantages over the systems conventionally used for this purpose:

- a) At a given transmission this type of baffle system gives a somewhat better resolution.
- b) Positioning of the outer envelope and the inner defining ring are equivalent to changing the maximum and minimum angles accepted from the source.
- c) A much lower background can be obtained since only electrons with a very definite trajectory can pass through the ring focus system.

Once the minimum width of a monoenergetic electron bundle was defined by F1 and F2 (for a solid angle of acceptance from the source of 3% of 4π), finer adjustments of the resolution and transmission were performed in two ways: (a) by moving the inner defining ring F2 in and out, which required breaking the vacuum, or (b) moving the outer envelope F1 along the axis simply by turning rod R1 from outside the spectrometer. Rod R2 merely prevents the envelope F1 and supporting structure from twisting.

Several interesting facts were found during the film exposures. The width of the electron bundle at the ring focus is the same as the diameter of the source. After the ring focus there is a rapid divergence of the electron bundle making it necessary to use rather large detectors. For a transmission of 3.0% a Livermore plastic scintillator D of the shape shown in Fig. 3 was used. This plastic scintillator had a maximum diameter of 4.5 cm and was 4.5 cm long. For transmissions of 2.0% or less an anthracene crystal 1-1/2 inches in diameter by 1/4-inch or 1/8-inch thick was used.

4. Performance of Spectrometer

a. Resolution and Transmission.

The performance of the assembled spectrometer was studied using a 4mm-diameter electroplated Bi²⁰⁷ source for which the absolute disintegration rate had been determined. The north end of the spectrometer (Magnet 2) was assembled first and a more exhaustive investigation was carried out on this side. By careful adjustments of the positions of the magnets and the

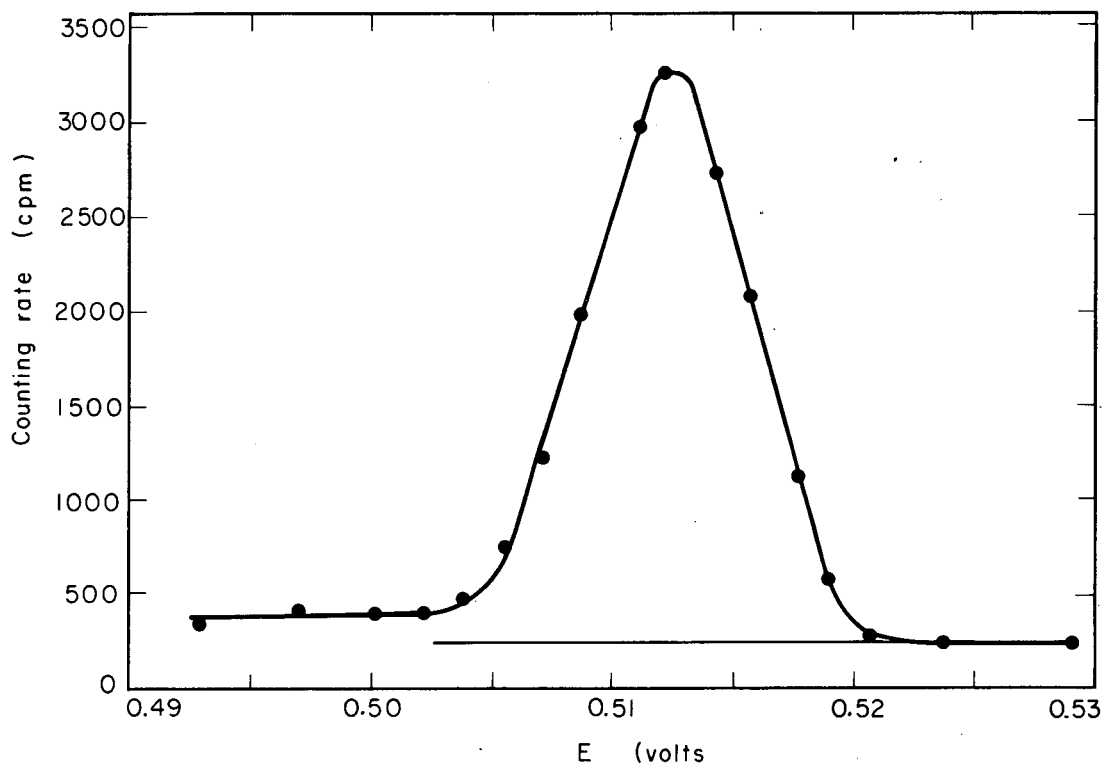
ring focus assembly, resolutions of 3.0 ± 0.1 and $1.7 \pm 0.1\%$ were achieved at transmissions of 3.0 ± 0.3 and $1.7 \pm 0.2\%$ respectively. The different resolutions were obtained by changing the position of the inner defining ring (F2 Fig. 3). These characteristics are identical to those of the Gerholm spectrometer for a 4mm diameter source. The resolution and transmission of 1.7% are not entirely determined by the finite source and the definition of the electron trajectories. The current regulators on both sides of the spectrometer were not functioning according to specifications. The specifications of 1953 were for current regulation of better than one part per thousand. At the start of this work the current regulation for the magnet 1 and 2 systems were found to be 1/300 and 1/400 respectively. A fair amount of time was devoted to improving the current regulation and they were improved to 1/400 and 1/500 respectively. These figures are consistent with the best current regulation previously achieved with this system. This poor current regulation contributes roughly 10% of the line width at 1.7% resolution. With an improved current regulation of 1/1000 as previously specified, a better resolution and transmission would be achieved.

The south lens (Magnet 1) was assembled to yield a 1.7% resolution and a 1.7% transmission. No further investigation of the dependence of transmission on resolution was conducted for this side of the spectrometer.

Figs. 5 and 6 show the spectrum for the K-conversion electron line of the 570-keV transition in Pb^{207} at a resolution of 1.7%. The abscissa represents the potential across a standard 0.080 Ω resistor in series with the magnet windings. The slightly different currents required to focus the same energy electrons in both halves of the spectrometer are due to the fact that slightly different minimum and maximum angles were accepted.

The current required to focus a given energy electron was found to be proportional to the momentum of the electron for each half of the spectrometer. The modified spectrometer requires currents of approximately 1.75 times that in the original spectrometer to focus an electron of a given energy.

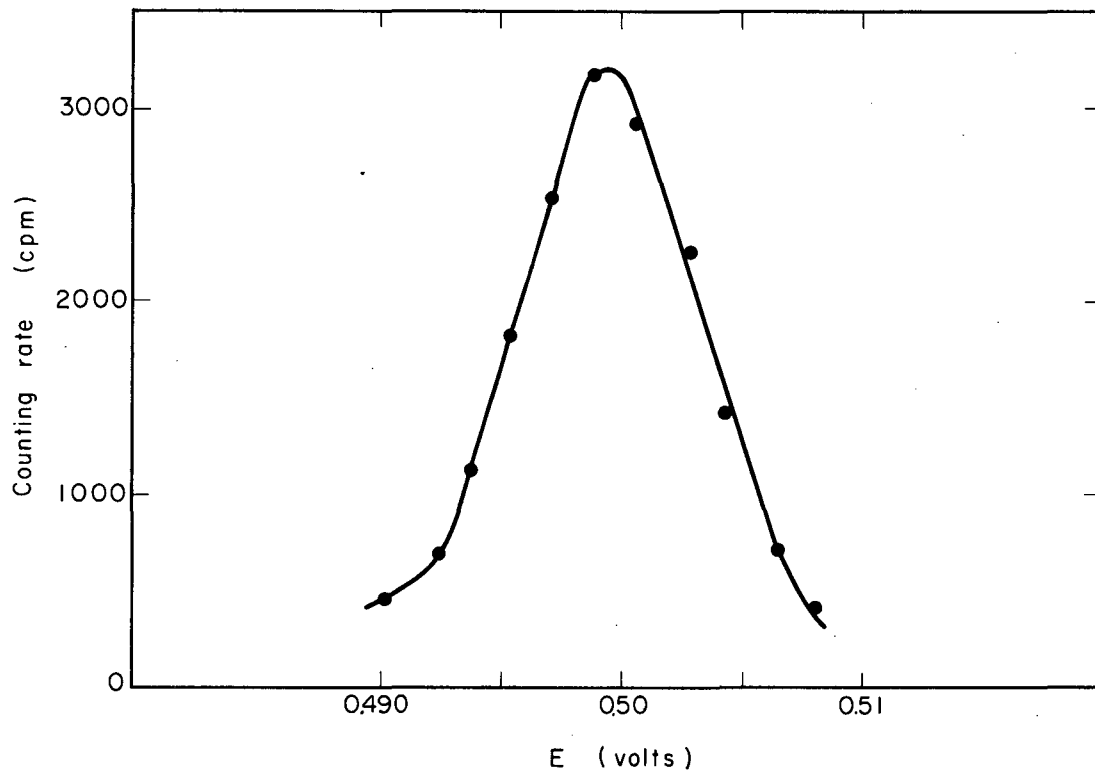
The mild steel rings (I1 and I2 Fig. 3) and the iron band (I2) around the center section did not completely isolate each half of the spectrometer from the magnetic field in the other half. The current required to focus a given energy electron in one side of the spectrometer is dependent on the current in the other side. Fig. 7 shows the dependence of the momentum calibration on the current in the other side of the spectrometer. The shape



MU-20636

Fig. 5. Magnet 1: K line of 570-keV transition in Pb^{207} .

Resolution = 1.74%
Transmission = 1.67%



MU-20637

Fig. 6. Magnet 2: K line of 570-keV transition in Pb^{207} .
1.7% resolution
1.6% transmission

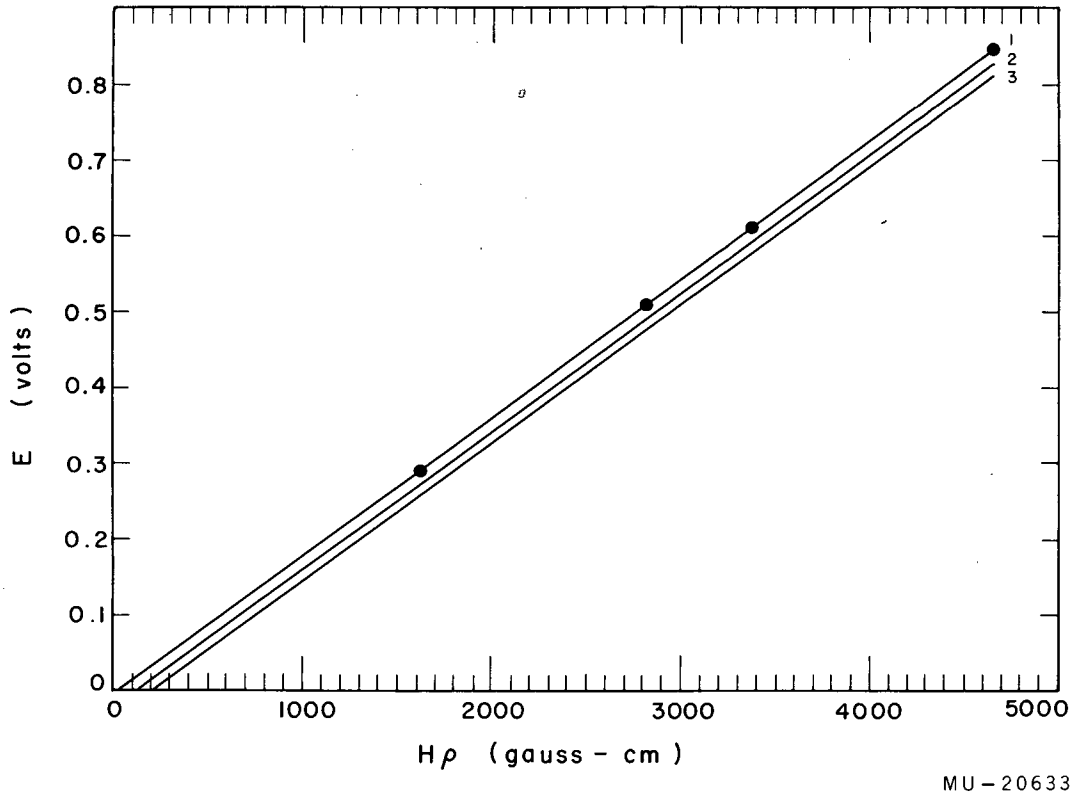


Fig. 7. Magnetic rigidity $H\rho$ vs. voltage in potentiometer circuit.
Magnet BRS-IV

1. $E' = 0$
2. $E' = 0.3115$
3. $E' = 0.61970$

and transmission of a given conversion electron line in one side of the spectrometer is not affected by the current in the other side of the spectrometer.

This interdependence of the current calibrations is clearly a non-desirable feature since if the current in one side of the spectrometer is changed, this change must be compensated for in the other side. Further isolation of both halves of the spectrometer will be very difficult. It could be achieved by: a) large extensions of the mild steel rings; b) completely cladding the whole spectrometer in iron; c) providing compensating coils.

For magnet currents larger than that required to focus a 1.1-Mev electron there is appreciable heating of the magnets and also the iron cylinder becomes saturated in the large magnetic field. These difficulties severely limit the use of the spectrometer above 1.1 Mev. However this limitation is not serious since: a) coincidence work with electrons more energetic than 1.1 Mev is rarely possible because of the low abundances of these transitions and their very small conversion coefficients; b) most beta spectra to excited states are less than 1.1 Mev.

b. Source Position.

The source positioning for a 4mm-diameter source has been found to be very critical. Displacement of ± 2 mm from the true position will result in a serious loss in transmission and resolution. Fig. 8 shows the dependence of the spectrum of the K-conversion electron of the 570-kev transition in Pb^{207} on the source position. The zero position in Fig. 8 is ~ 0.5 mm from the true zero position.

5. Counting System

The light output of the scintillators is converted to electronic pulses using RCA-6810A photomultiplier tubes. These phototubes are high gain 14-stage tubes with a partially curved photocathode surface to minimize photoelectron transit time spreads between the cathode and the first dynode.

The basic coincidence circuit used is of the fast-slow type employing a time-to-pulse-height converter as the fast counting element in conjunction with a 100-channel PENCO pulse-height analyzer, Fig. 9. A standard fast coincidence unit is also provided to be used in place of the time-to-pulse-height converter when the coincidence counting rates are simply recorded on a scalar. The time-to-pulse-height converter and the coincidence circuit

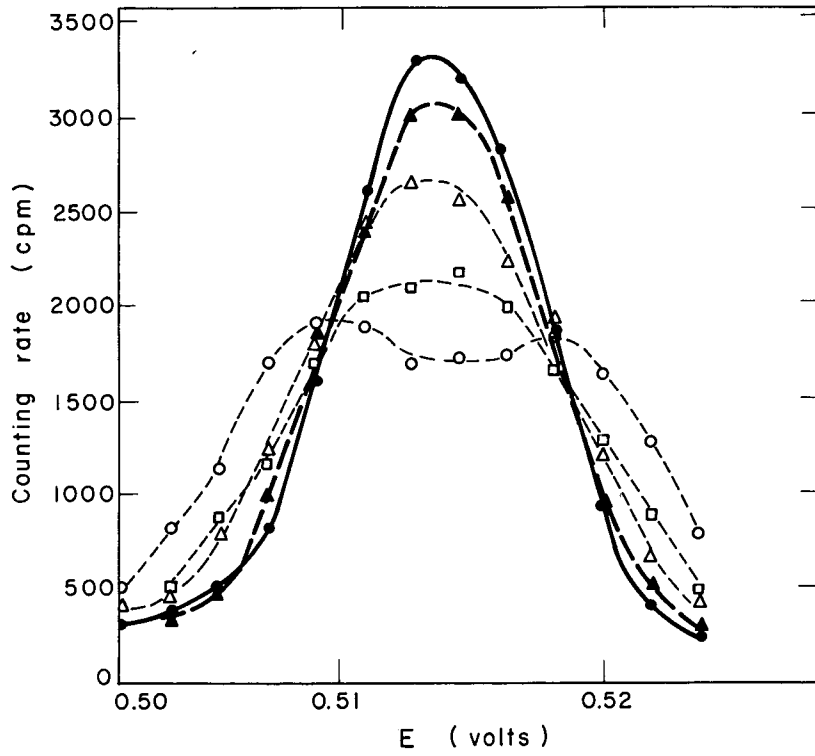
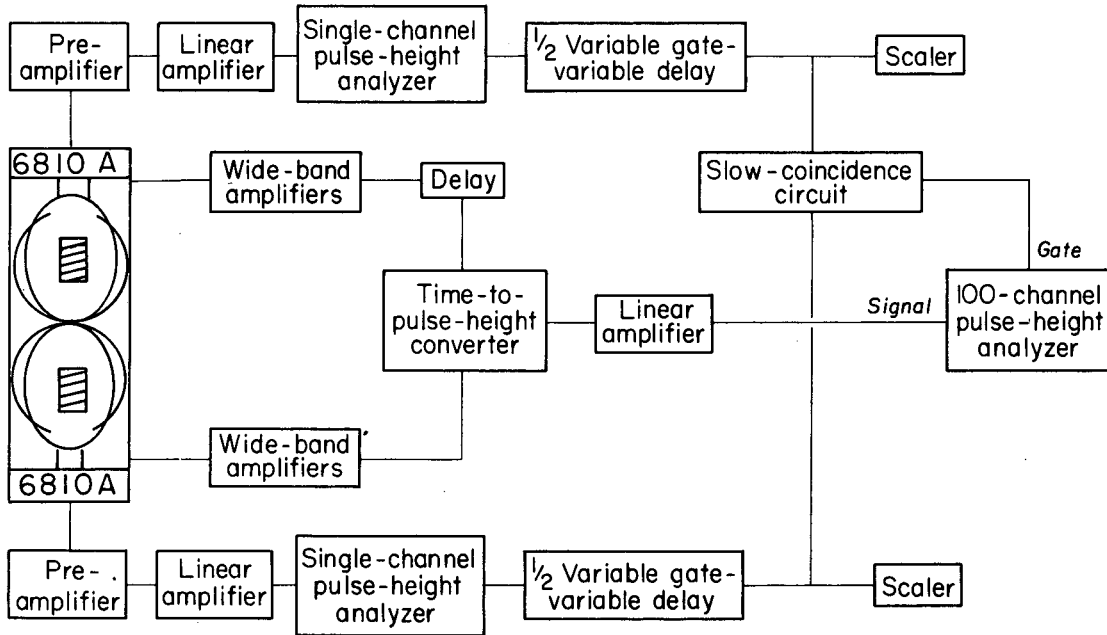


Fig. 8. Magnet 1. K conversion electron line of the 570-keV transition in Pb^{207} as a function of source position.

— zero from film emulsion work
— + — 0.13 cm
- - □ - - 0.26 cm
+ + ◇ + + + 0.13 cm
+ + ○ + + + 0.26 cm



MU - 19742

Fig. 9. Block diagram of millimicrosecond coincidence circuit.

have previously been described [JU60].

The pulses for the fast coincidence analysis are taken directly from the anode of the phototube. For electron energies greater than 60-keV, the gain of the phototube is so large that the wide-band amplifiers are not necessary. The pulse height from the anode is sufficient to activate the time-to-pulse-height converter. The pulses for the slow analysis, generally used to discriminate against phototube noise and excessive low energy background are taken from the twelfth dynode to insure linearity.

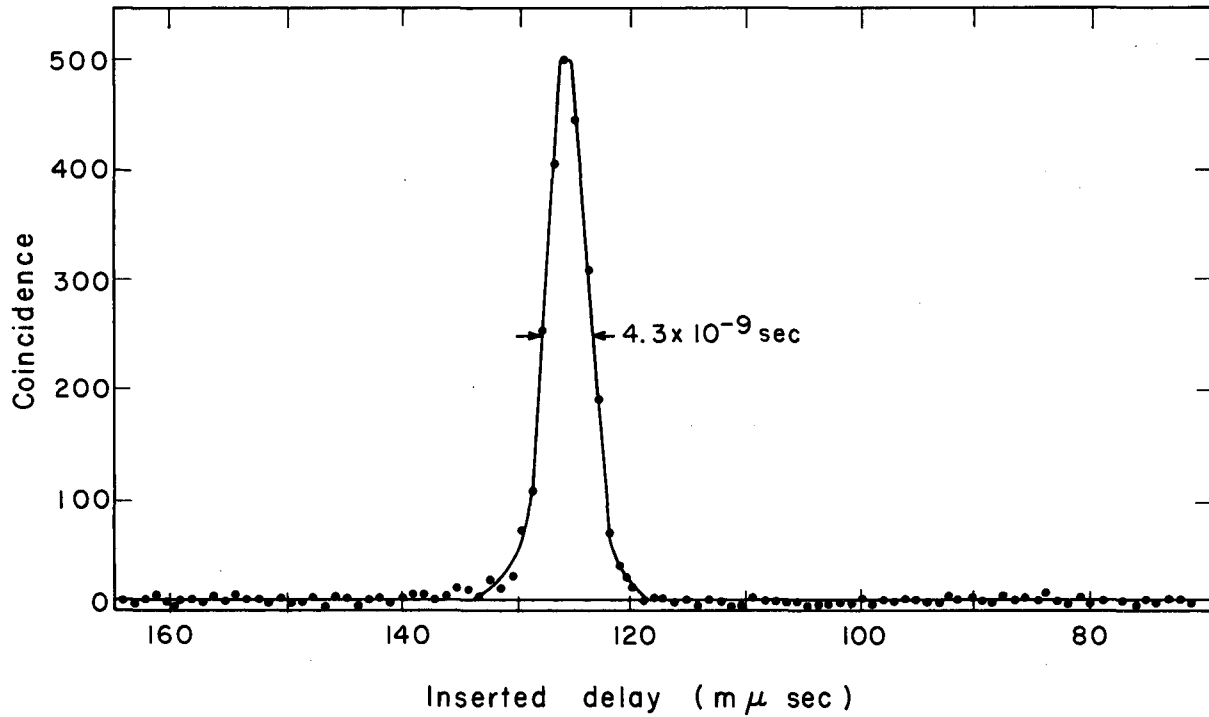
A display of the time relationship between pulses from each side of the spectrometer represents a considerable improvement over the conventional coincidence methods. From this type of display the chance coincidence counting rate is very easily determined since the chance events occur randomly in time and appear as a constant background on the 100-channel pulse-height analyzer. The time coincidence events on the other hand appear as a peak in this type of display.

Fig. 10 shows a prompt coincidence spectrum superimposed on a chance spectrum for 104-keV beta particles in coincidence with the 193-keV K-conversion electrons in the decay of Hg^{203} . In addition to simultaneous recording of true and chance coincidences, the time relationship between the two electrons and hence information on the lifetime of the intermediate state, is also obtained.

D. Discussion

This modification of the spectrometer has decreased the source-to-detector distance from 100 cm to 40 cm and has increased the maximum solid angle accepted from the source from 0.4% to 4% of 4π . As a comparison, the source-to-detector distance in the Gerholm spectrometer is 25 cm and the maximum solid angle is 5%.

Since the coincidence counting rates are proportional to the product of the transmissions of both halves of the spectrometer, this modification has increased the coincidence counting rates by a factor of 100 over that of the original spectrometer for a resolution of 2%. Also the spectrometer is now capable of operating at 1.7% or 3% resolution in both halves with increased coincidence counting rates of 70 and 225 times, respectively, that of the original spectrometer.



MU-20639

Fig. 10. Prompt coincidence and chance time spectrum for 193-keV K-internal conversion electrons in coincidence with 104-keV beta particles in the beta decay of Hg²⁰³.

II. ELECTRON-ELECTRON COINCIDENCE SPECTROMETER-USE

A. Introduction

The following section of this report describes the actual use of the spectrometer. It is the hope of this author that future readers will save valuable time by reference to facts and suggestions concerning the operation of the spectrometer contained in this report.

A picture of the control panel of the spectrometer is shown in Fig. 11 and will be used as a guide to components described and referred to in the text.

B. Sources

Since electrons must pass through the source backing material, considerable attention must be devoted to preparation of source backings very thin in relationship to the range of the electrons under investigation. There are two general classes of backing material — plastics and metals, and three general methods of preparation: a) evaporation, b) electro-deposition, and c) vacuum volatilization. The reader is referred to a recent review article by Parker et al. concerning source preparation.⁹

1. Materials.

a. Plastics

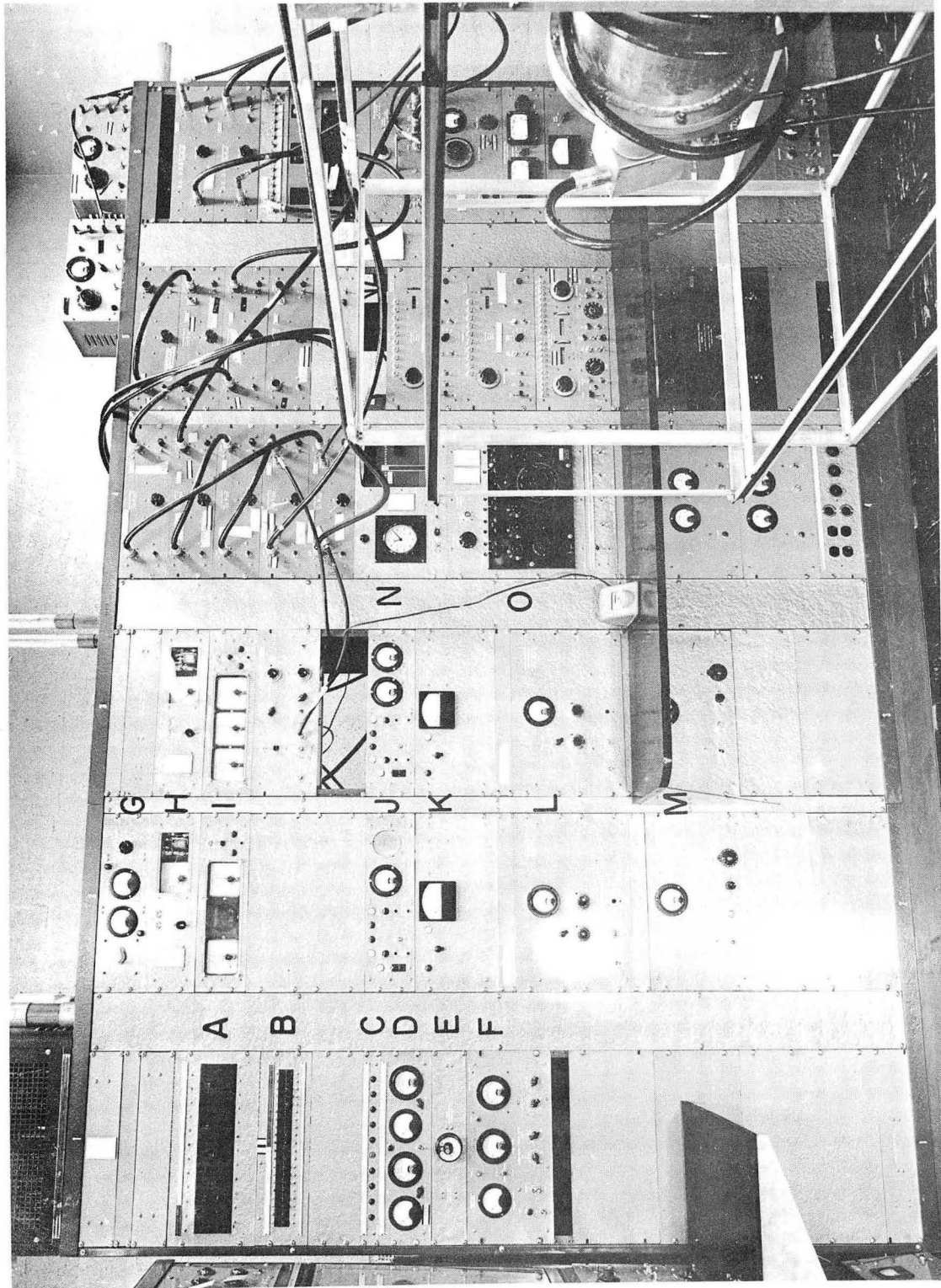
Two plastics films have been used in this work — Zapon and VYNS. Zapon films can be made from several $\mu\text{-gm}/\text{cm}^2$ to several mg/cm^2 .¹⁰ The VYNS films can be conveniently made from $\sim 1 \mu\text{gm}/\text{cm}^2$ to $\sim 20 \mu\text{gm}/\text{cm}^2$.¹¹ The VYNS films used by this investigator were prepared by Daniel O'Connell (Bldg. 64). The films consist of two laminated layers of $10 \mu\text{gm}/\text{cm}^2$ film with a very small amount of aluminum or gold vaporized in the film to provide a conducting surface. The films are laminated to minimize the possibility of weak spots. The VYNS films have been found to be much more useful in this work and are less susceptible to tearing or being attached by acids. Aluminized mylar of $0.74 \text{ mg}/\text{cm}^2$, and $1.4 \text{ mg}/\text{cm}^2$ Teflan sheets are commercially available and should prove to be very useful source backings.

b. Metals

Aluminum foils thicker than $0.2 \text{ mg}/\text{cm}^2$ are commercially available.

FIGURE LEGEND for Figure 11.

- Control panel for the electron-electron coincidence spectrometer.
- A. Main power switches.
 - B. Minor power switches.
 - C. Operational lights for vacuum pumps.
 - D. Vacuum thermo-couple gauges.
 - E. Diffusion pump high-pressure relay.
 - F. Ion gauge control.
 - G. Regulated voltage control.
 - H. Magnet Current relays.
 - I. Magnet temperature gauges and water pressure indicating lights.
 - J. Individual current regulator control switches and operational lights.
 - K. Magnet current meters.
 - L. Magnet current amplifiers.
 - M. Filter amplifiers.
 - N. Timer and galvanometer.
 - O. Potentiometer.



ZN-2612

Fig. 11.

2. Source Preparation.

a. Evaporation

Uniform sources of ≥ 2 mm diameter can be prepared by evaporation of droplets of solution onto the films using the insulin wetting technique. The droplet of active solution is prevented from spreading over the film surface by first forming a thin layer of protein over the desired area of the film. A drop of insulin solution diluted with 20 parts of water is put on the film spot desired for the source and the excess insulin solution is then removed with a pipet. When a droplet of radioactive solution is placed on this wetted area it will spread uniformly over the area and generally not spread any further.

Recently, the technique of electrostatic spraying has been applied to preparation of thin uniform sources by Ghiorso. Using this technique this author has prepared 2mm diameter Co^{137} sources. This technique requires that the activity be soluble or suspendable in a rather volatile solvent. In the case of Co^{137} , $\text{Co}(\text{NO}_3)_2$ is soluble in acetone. If the reader is interested in this technique he should contact A. Ghiorso or Helen Michel.

b. Electro-deposition

Very small uniform sources can be prepared by electro-deposition. The applicability of this method depends on the backing material desired and the electro-deposition yield. Bi^{207} sources of 1mm diameter can easily be prepared by electro-deposition onto copper foils from sulfuric acid solutions. The area of the foil except for the desired 1mm diameter spot is coated with fingernail polish, glyptal paint, or zapon to prevent electro-deposition on this surface.

Sibman has described electro-deposited of activities onto thin silver coated mylar foils.¹²

c. Volatilization

Very small homogenous sources can be prepared by thermal evaporation or distillation in vacuum. Numerous references are given in the literature to this type of source preparation for a wide variety of elements. Stockendel and Bergkvist in particular describe an evaporation device for beta spectrometer sources.¹³ They have used this device to prepare bismuth, lead and thallium sources with yields from 50 to 90%.

3. Source Position.

Source alignment can only be adjusted in the horizontal position with the present source probe so great care should be taken to place the active material in the center of the source holder ring. The most ideal source position should be determined experimentally for each source. A source centered at $X = \frac{15}{32}$ inch will be at the correct source position, Fig. 12.

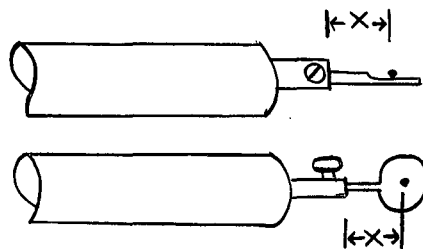


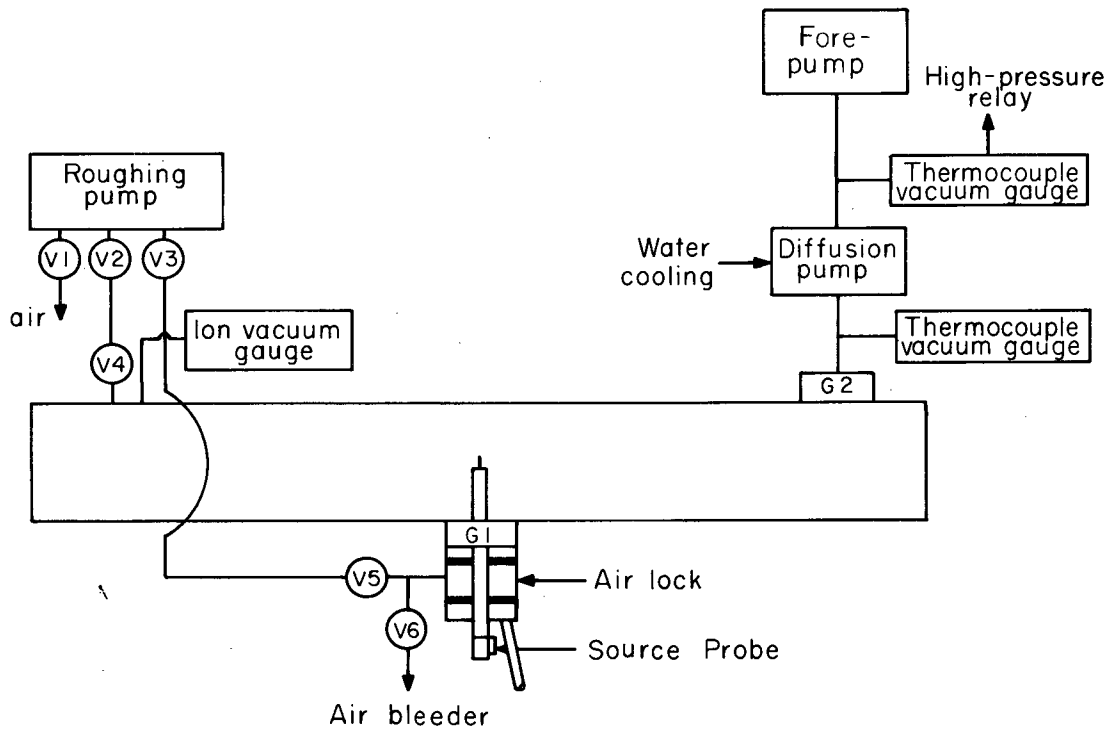
Fig. 12. Source holder on probe.

C. Vacuum System

Fig. 13 shows a block diagram of the present vacuum system. Three vacuum pumps are normally used: a roughing pump, a diffusion pump, and a fore pump. The switches for the roughing pump and the fore pump are located in panel A of Fig. 11. The switch for the diffusion pump is located in panel B. Two vacuum gauges monitor the tank pressure, an ion gauge (panel F) and a thermocouple gauge (panel D). There is also a thermocouple gauge (panel D) monitoring the pressure on the back side of the diffusion pump. In order that excessive back pressures on the diffusion pump do not occur (in case of a vacuum tank leak, failure of fore pump, etc.) a high pressure relay (panel E) is connected to the thermo-couple gauge. In case of excessive backpressures—pre-set on the relay—the diffusion pump will shut off. Water cooling is necessary for the diffusion pump. The valve for the water cooling is located in the north-west corner of the room. The operational lights in panel C indicate if the fore pump, roughing pump and diffusion pump are on, and also if the high pressure relay is cut off.

Evacuation of Spectrometer

- 1) Roughing pump on
- 2) Only valves V2 and V4 open



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Fig. 13. Block diagram of vacuum system.

If fast evacuation is desired < 1 hr and diffusion pump is cold.

2a) After tank pressure is reduced to ~500 μ with roughing pump — open G2 — and allow the fore pump to pump on the spectrometer through the cold diffusion pump.

3) When tank pressure is less than 80 μ — close G2 and turn on water cooling and diffusion pump. Never turn on diffusion pump without the fore pump going and never turn off fore pump when diffusion pump is hot!!

4) After diffusion pump is hot and back pressure is < 30 μ — open G2.

5) Close V4

6) Diffusion pump will only function when tank pressure is initially less than 80 μ .

7) Never operate diffusion pump with back pressures greater than 200 μ .

Sample Introduction

There are three important things to remember:

a. Always have the interior of the air lock evacuated when moving the source probe in and out of the evacuated spectrometer from the air lock or opening and closing G1.

b. Always open valves V5 and V6 to air lock slowly to avoid a sudden rush of air which may break the sample.

c. Always close G1 when air lock is to be at atmospheric pressure.

Sample in:

1) Push probe into air lock to stop provided.

2) With V1, V2, V4, V5, V6 closed, open V3.

3) Open V5 slowly.

4) Wait until air lock is evacuated ~ 1 min

5) Close V5.

6) Open G1

7) Push probe all of the way in.

Sample out

1) With V1, V2, V4, V5, V6 closed, open V3

2) Open V5

3) Wait until air lock is evacuated

4) Pull probe out to stop

5) Close G1

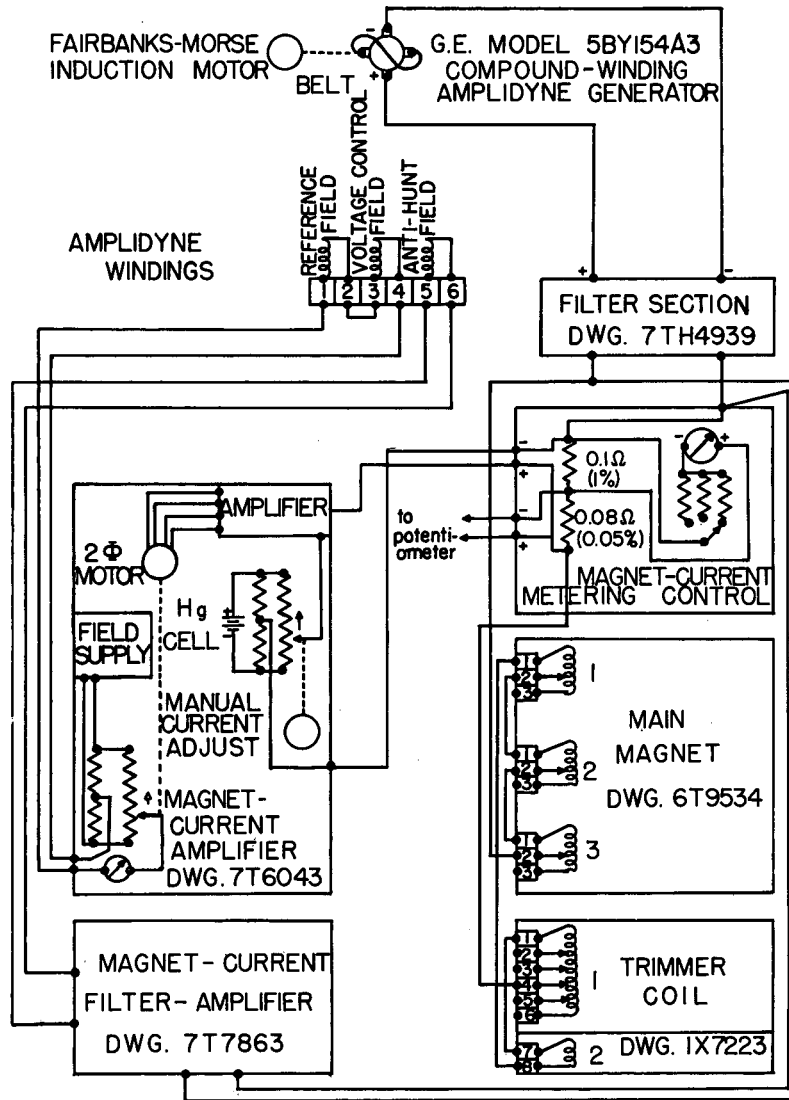
6) Open V6 slowly

7) Pull probe all the way out.

D. Magnet Current Supply

The two spectrometer units have similar independent magnet power supplies; thus the following description applies to either of the two spectrometers. A block diagram of the magnet current supply is shown in Fig. 14. The magnetic coils obtain their power from a General Electric amplidyne generator, model 5BY1543, which delivers 20 amp at 250 v. This is belt-driven by a Fairbanks-Morse induction motor type QZK, which is rated at 2890 rpm with a full load. Three of the four amplidyne windings were used, with the first two connected in series. The three windings are designated respectively as the reference field, voltage control field, and the anti-hunt field windings. The dc output of the amplidyne is filtered by a filter section to remove some of the ripples present that are caused by the noise from the brushes and armature of the generator. In series with the dc output is the magnet-metering section where a 0.08000 ± 0.00004 -ohm manganin temperature-independent-type resistor and a 0.1000 ± 0.001 -ohm precision wire-wound resistor are used to measure the current going to the magnet. A Rubicon No. 2780 potentiometer, standardized against an Epply No. 100 standard cell using a Leeds and Northrup type 2420C galvanometer, determines the potential drop across the manganin resistor, while a direct-reading ammeter with ranges 0 to 1, 0 to 10, and 0 to 25 amp is connected to the 0.1000-ohm resistor. After being filtered and measured, the current goes to the magnets. The main and trimmer coils are connected in series and with opposing magnetic fields.

To stabilize the power in the magnetic coils, the potential drop across both the 0.08000- and the 0.1000-ohm resistor of the magnet-metering section is fed into the magnet-current amplifier where it is continuously compared to the potential supplied by four mercury cells spot-welded together. The amount of reference potential from the mercury cells is determined by connecting a 5000-ohm Helipot resistor to the manual current control. Any excess unbalance current between the reference potential and the potential drop across the resistors of the magnet-metering section is detected and amplified by a Leeds and Northrup amplifier. The amplifier sends correcting signals to a 2-phase motor which is connected through a clutch to a 100-ohm Helipot resistor that controls the field current being fed to the reference and voltage-control amplidyne windings. Hence, any increase or decrease in the current output of the amplidyne would be detected by the



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Fig. 14. Magnet-current block diagram.

amplifier and would result in the decrease or increase of the amplidyne field current until the normal current output is obtained. With this arrangement, variations in current of up to 9 cps are corrected. For fluctuations of from 9 to 60 cps, the filter amplifier section of the dc power supply to the magnet can compensate within a second. In this setup, no precaution was deemed necessary for stray pulses greater than 60 cps because such high-frequency noise is essentially short-circuited by the large capacitors located in the magnet-current filter amplifier.

The main power switches for the generators on the roof are in panel A of Fig. 11. The power switches for the current regulator controls are located in panel B. Magnet 1 and Magnet 2 refer to the south and north sides of the spectrometer respectively.

The current in the magnets cannot be turned on unless there is sufficient cooling water flowing in the magnets. The water flow is indicated in Panels I as "Water Flow" or "Water Failure". The value for the cooling water is located on the west wall of the room in the north-west corner. The procedure for magnet operation is as follows:

1. Starting with all switches in Panels J, L, and M off and Magnet 1 and 2 switches in panels A and B off.
 2. Turn on Magnet 1 and 2 switches panel A
 3. Turn on Magnet 1 and 2 control switches panel B
 4. Turn on both Current Regulator Power switches panels J
 5. Turn on both Filter Amplifier switches panels M
 6. Turn on cooling water for magnets.
 7. The following operational lights should be on:
 - a) "Water Flow", panels I
 - b) Current Regulator Power, panels J.
 - c) Motor Ready, panels J.
8. Important! Push "Motor Run" button panel J and at same time turn on Magnet Current Amplifier switch panel L.
 - a) Motor generators will start
 - b) "Motor Run" light, panel J, is on
 - c) Current in ammeter, panel K, goes up to ~ 2 amps
 - d) "Ready for Field" light goes on, Panel J.

It is important that the "Motor Run" button and the Magnet Current Amplifier switch be turned on simultaneously. If the Magnet Current Amplifier

switch is turned on and there is no current flowing from the generator, an electric motor will drive the 100-ohm Helipot resistor as far as it will go, trying to seek a balance. If this occurs and then the "Motor Run" button is turned on, starting the generators, the current in the magnets will rise rapidly to 20 amperes, the circuit will overload and a high current relay will be cut off. This tremendous increase in the magnetic field that is produced will create a large force on the iron cylinder inside the spectrometer. Severe damage to the baffle system can occur if this happens.

9. When "Ready for Field" light, panel J, goes on and the current in the ammeter, panel K, is no longer rising rapidly, push "Field Relay" on button, panel J. The spectrometer is ready for operation when steps 8 and 9 are completed for both magnet systems.

The desired magnet current required to focus a given energy electron can now be obtained by adjusting the fine and coarse controls of panels L. To achieve a stable current a null point must be obtained on the meters of the Magnet Filter units, panels M. This is achieved by

1. Depressing the red button
2. Adjusting the control so that the needle fluctuates about zero.

This null point must be checked periodically, and in particular when changing the current in the magnets, to achieve the best current regulation possible.

An estimate of the current can be obtained from the ammeters of panels K. More accurate determinations of the current required for the electron energy calibrations can be obtained by using the potentiometer circuit panels O and N. This potentiometer measures the voltage drop across a standard 0.08-ohm resistor in series with the magnet windings.

To Shut off Current:

1. Set current in magnet to some low value ~ 1 amp
2. Adjust null point on Magnet Filter Unit.
3. Press "Field Off" button, panel J
4. Press "Motor Step" button, panel J, and turn off Magnet Current Amplifier switch simultaneously.

This procedure guarantees that the 100-ohm Helipot resistor will be at the proper position when the current is next turned on.

E. Spectrometer Calibration

The calibrations given in this section are to be used when the spectrometer is operating at 1.7% resolution and 1.7% transmission (present status of spectrometer, June 1960).

Figs. 15 and 16 show the calibration of the electron magnetic rigidity H_p as a function of the potential E across the 0.08-ohm resistor in series with the magnet windings and also the potential E' across the 0.08-ohm resistor in series with the magnet windings of the other half of the spectrometer. These calibrations were performed using the K-internal conversion electron lines from the decays of Hg^{203} , Bi^{207} , and Cs^{137} . The experimental values of E and E' were related to the electron magnetic rigidity using the following two expressions:

$$H_p = k_1 E + k_2 E' \quad (2)$$

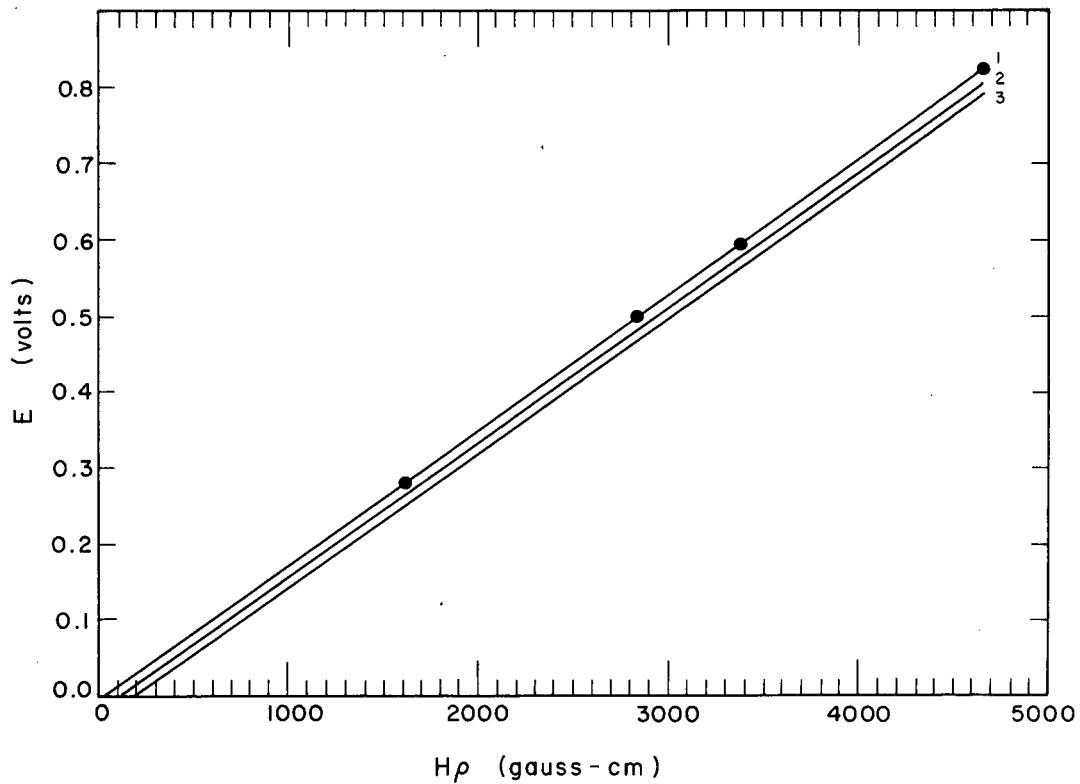
$$H_p = k_3 E + k_4 + k_5 E' \quad (3)$$

A summary of the constants is given in Table I.

TABLE I

| BRS-IV Calibration Constants | | | | | | | |
|------------------------------|--------|-------|--------------------------------|--------|-------|-------|--------------------------------|
| Magnet | k_1 | k_2 | $\frac{\Delta H_p}{H_p}$ (100) | k_3 | k_4 | k_5 | $\frac{\Delta H_p}{H_p}$ (100) |
| 1 | 5542.2 | 289.7 | 0.8 | 5463.5 | 37.7 | 285.6 | 0.45 |
| 2 | 5682.1 | 301.4 | 0.86 | 5616.9 | 30.4 | 297.3 | 0.58 |

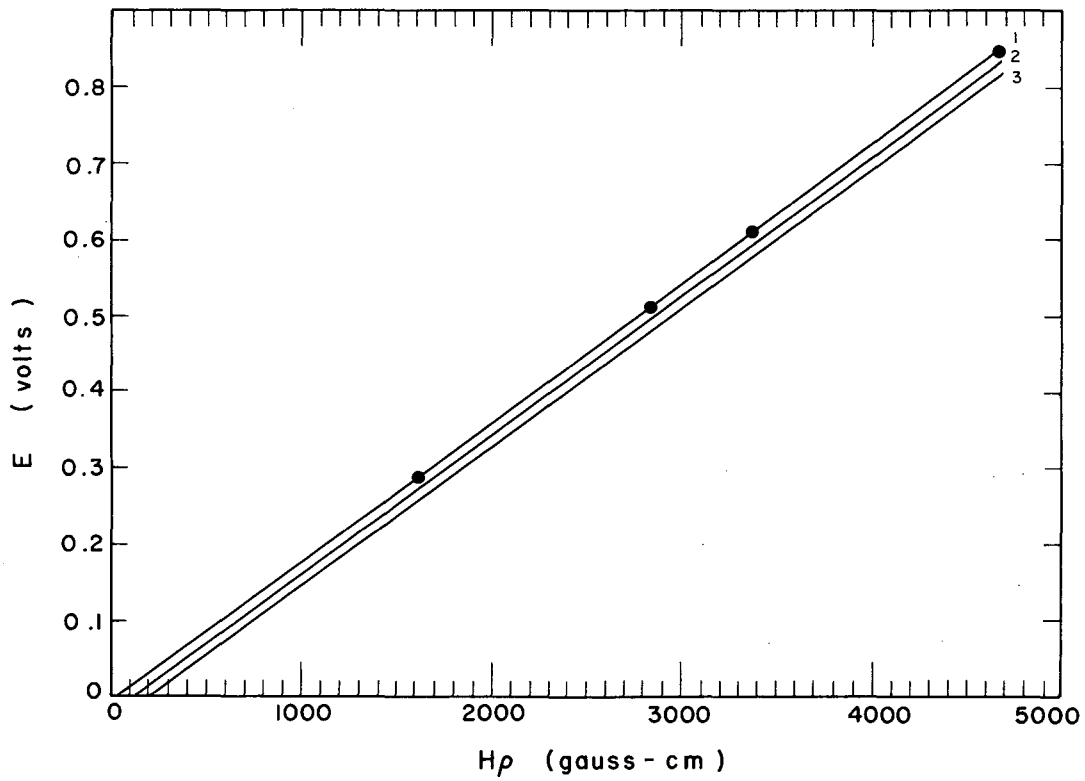
Columns 4 and 8 give the maximum errors in the magnetic rigidities calculated with the appropriate expressions in the range of $H_p = 1617.7$ to 4657.9 and E' from 0 to 0.61970. The reason why a constant k_4 in expression 3 should give a better fit than the pure linear expression 2 is not understood at present. The constant k_4 may indicate that a remanent magnet field exists



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Fig. 15. Magnetic rigidity $H\rho$ vs voltage in potentiometer circuit.
Magnet 1 BRS IV

1. $E' = 0$
2. $E' = 0.3115$
3. $E' = 0.61970$



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Fig. 16. Magnetic rigidity $H\rho$ vs voltage in potentiometer circuit

Magnet 2 BRS IV

- 1. $E' = 0$
- 2. $E' = 0.3115$
- 3. $E' = 0.61970$

in the spectrometer due to the mild steel used in the construction. Also this constant is needed mainly to fit the data for the 194-keV conversion electron in the decay of Hg^{203} . This source contained appreciable mass due to the rather low specific activity and appreciable scattering and energy loss may have occurred in the source.

F. Solenoids for Phototube Shielding

Fig. 17 shows the relationship between the minimum current required in the solenoids for adequate magnetic shielding of the phototubes and the coarse dial setting on the current regulators. After the threshold for use of the solenoid has been reached solenoid currents greater than the given minimum values and less than 0.5 amperes will not affect the phototube operation. It is therefore convenient to set the solenoid current at the appropriate value corresponding to the highest magnet current to be used when scanning a spectrum above the threshold for use of the solenoid.

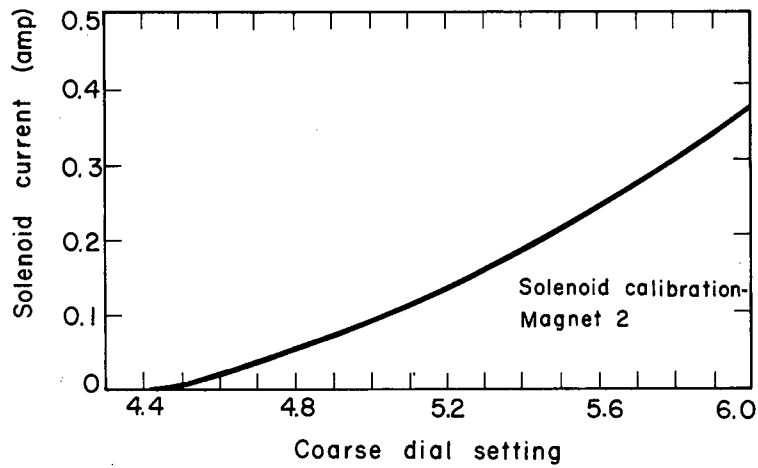
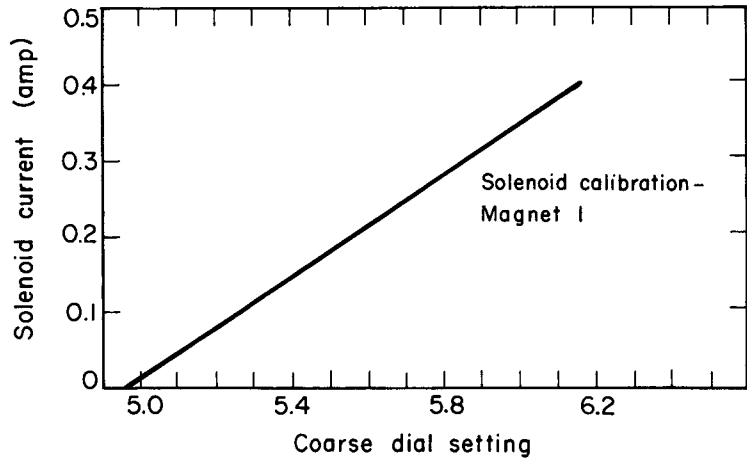
The solenoid for Magnet 1 is an early design and does not have adequate cooling. Therefore this solenoid should be used for very short counts ($\sim 1/2$ hr. for currents in excess of ~ 0.25 amperes). The solenoid for Magnet 2 is properly constructed and can be used indefinitely without appreciable heating for currents less than 0.5 amps.

G. Additional Comments (June 1960)

The spectrometer is presently set for 1.7% resolution and 1.7% transmission. The resolution and transmission can be changed by a simple adjustment of the inner defining ring of the baffle system.

There is presently 0.74 mg/cm^2 aluminized mylar covers over the anthracene crystals. This thickness corresponds to an appreciable fraction of the half thickness for a 60-keV electron. For the study of low energy electrons $\sim < 80$ -keV this cover should be removed.

The pulse-height output of the photo multiplier for a 60-keV electron is comparable to the phototube noise level. Cooling the phototube by simply packing dry ice into the end of the brass pipe will lower the noise level appreciably.



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Fig. 17. Solenoid calibrations— minimum solenoid currents required for photomultiplier tube operation.

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