A LOW ENERGY BETA-RAY SPECTROMETER

by

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ABSTRACT

The construction and preliminary tests of a Beta-ray spectrometer designed to work at energies below 100 Kev is described. The instrument is of the small semi-circular focussing type using four counter pairs. The design is for reasonably high resolution and high transmission angle.

The magnetic field is produced by a combination of plane coils designed to maintain field homogeneity to better than 1%. The magnet current is held to 1 part in 10,000 by means of an electronic circuit composed of D.C. and A.C. amplification stages controlling the grids of a bank of 6AS7 double triodes in series with the magnet windings.

The counter windows and source backing are colloid films of the order of 0.1 μ. Work on this instrument is continuing.
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A LOW ENERGY BETA-RAY SPECTROMETER

I. INTRODUCTION

In extending the range of ordinary methods of Beta-ray spectroscopy to low energies a number of difficulties arise. The most important of these are as follows:

(a) The scattering of electrons from parts of the apparatus increases greatly at lower electron energies. From theoretical considerations the scattering, in the two processes important at low energies, ionization and elastic scattering, varies inversely as the energy to the first power, at least, and directly as the atomic number of the scattering material. Experimentally the work of Schonland\textsuperscript{1} on the scattering of cathode rays has shown that approximately this holds true.

(b) The detection of low energy Beta particles also presents difficulties. If the ordinary Geiger counter is used the 'window' must be made extremely thin in order to

allow the passage of the particles into the counter chamber. Even here scattering is still the major problem as Crowther\(^2\) has found that Beta particles are strongly scattered by films so thin that absorption is inappreciable.

The method of mounting the radioactive source becomes very important at low energies. Unless it is mounted on a very thin film an excess of low energy electrons is caused by scattering from the support. The work of Flammersfeld\(^3\) and Tyler\(^4\) has shown the importance of this back scattering.

(c) At low energies it becomes difficult to measure the deflecting magnetic field to the accuracy required. In an ordinary large scale spectrometer fields of less than 30 gauss may be required to focus electrons of 10 Kev energy. Thus calibration to one percent entails measurement of a fraction of a gauss.

(d) At these low field strengths the effect of extraneous magnetic fields becomes important. In particular, compensation for the earth's magnetic field is critical particularly when it has a component perpendicular to the focussing field.

For these reasons very few authors have quoted results for Beta spectra below 100 Kev. Any measurements that have been obtained in this region have been the result

\(^3\)A. Flammersfeld, Zeits.fur.Physik 112, 727, 1939.
\(^4\)A. W. Tyler, Phys.Rev. 56, 125, 1939.
of special techniques.

The work of Backus\textsuperscript{5} on the Beta spectrum of Cu\textsuperscript{64} illustrates this. In investigating this spectrum down to 5 Kev he used an electrostatic focussing spectrometer. His counter windows and source backing were collodion films about 0.1 micron thick.

The small amount of work done below 100 Kev is due entirely to the experimental difficulties involved and not because of any lack of importance. On the contrary it is essential for the development of consistent nuclear theory that reliable information be available in the low energy region.

The quantum mechanical equation for the energy spectrum of Beta particles does not differentiate between positrons and electrons with the exception of an expression related to the Coulomb field of the nucleus. This expression is negligible except at low energies. Even on a classical picture it is evident that an electron spectrum should have some intensity even at zero energy while a positron spectrum should drop to zero intensity at an energy equivalent to the potential energy of a positron at the 'surface' of the nucleus. Backus\textsuperscript{5} in his investigation of the electron and positron spectra of Cu\textsuperscript{64} found a definite deviation from the low energy positron to electron ratio given by nuclear theory. A knowledge of the low energy spectra of many isotopes is essential to the development of a satisfactory nuclear theory.

\textsuperscript{5}J. Backus, Phys.Rev. 68, 59, 1945.
In addition it is highly probable that there are numerous undiscovered Beta groups whose end points are below 100 Kev. Also the energy and intensity of Gamma rays in this region are uncertain and require further investigation.

For these reasons it was decided to build a small spectrometer expressly to measure Beta spectra below 100 Kev. It could also be used to measure Gamma spectra in this region since the work of Robinson\(^6\) on photo effects of X-rays below 10 Kev shows that the 'photo-electron radiator' technique of Beta-ray spectroscopy can be applied even at very low energies.

The design of the spectrometer was governed by the following factors:

(a) In order to use current control apparatus already built for the large spectrometers magnetic focussing was chosen - utilizing the well known semi-circular focussing property of a magnetic field.

(b) An air-cored magnet must be used if possible so the field would be a linear function of the current - thus only one point calibration would be required.

(c) The spectrometer had to be as small as possible to give a small radius of electron path, to limit the size of the field producing coils and so that the entire apparatus could be lined up parallel to the earth's magnetic field in order to eliminate the need for compensating coils. A lower limit is imposed by the minimum size of the Geiger counters.

(d) All surfaces in the spectrometer must be made of a substance of low atomic number in order to reduce the scattering of electrons.

(e) In order to eliminate the use of heavy lead baffles to prevent gamma ray background the counters should be so arranged that a coincidence technique could be used if necessary.

(f) As large as possible a solid angle of the radiation from the source should be utilized so that weak sources could be investigated.

(g) As a preliminary figure a resolution of 1% was laid down, but the design of the spectrometer was to be such that changes in the baffle system, etc., could readily be made.

(h) The technique developed by Backus for thin counter windows was to be used if possible.

As the spectrum of Radium D has been found to consist of Beta's and Gamma's of very low energy, this substance was chosen to make preliminary tests of the instrument.

Radium D has been investigated by several workers, all using rather special techniques. G. von Droste using a Wilson cloud chamber and magnetic deflection, together with measurements of path lengths, obtained a series of β lines all attributable to the action of one γ line of 47.2 keV energy. Richardson and Leigh-Smith distributed Radium D as

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5J. Backus, loc. cit.
6G. von Droste, Zeits.fur.Physik 84, 17, 1933.
a gas in the form of tetra-methyl lead throughout a cloud chamber. The Beta spectrum was then calculated from electron path lengths and range-energy measurements. Lee and Libby\textsuperscript{9} using magnetic deflection and aluminum absorbers found a primary Beta-ray distribution of very low energy with an end point of $25.5 \pm 1$ Kev. Considerable work on the Gamma radiation of RaD has been done by Tsien San-Tsiang, Frilley, et al.\textsuperscript{10}, who report the existence of several nuclear Gamma rays of various intensities. By a number of methods, such as crystal analysis, cloud chamber path lengths, absorption measurements, etc., they show the existence of seven Gamma lines of energies from 7.3 Kev to 65 Kev.

\textsuperscript{9} D.D. Lee and W. F. Libby, Phys. Rev. 55, 252, 1939.
\textsuperscript{10} Tsien San-Tsiang, Comptes Rendus 216, 765, 1943.
Tsien San-Tsiang, Comptes Rendus 218, 505, 1944.
M. Frilley, Comptes Rendus 218, 505, 1944.
Tsien San-Tsiang and C. Marty, Comptes Rendus 221, 177, 1945.
Tsien San-Tsiang, Phys. Rev. 69, 38, 1946.
II. APPARATUS

The apparatus may conveniently be divided into three parts, the spectrometer itself, the magnet, and the current control apparatus.

A. THE SPECTROMETER

The design of the spectrometer itself is governed by requirements (c), (f) and (g) above. The basic design is as follows: The source is mounted on a vertical thread in the center of a circle. Symmetrically spaced on the circumference of this circle there are four Geiger counters. By the action of a magnetic field perpendicular to the plane of the circle, electrons emitted by the source travel in circular paths. Baffles are placed so that only electrons whose paths have diameters equal to the distance from the source to the counter window will reach the counter. The entire apparatus is enclosed in a cylindrical box which is evacuated.

Plan and section views of the spectrometer are shown in Fig. 1. The actual dimensions were calculated in inches because of difficulties with machine work and materials available.

The enclosing box is a brass cylinder of 6\(\frac{1}{4}\) inches
inside diameter with walls 3\春天 inch thick. The end plates are of 5/16 inch brass. Soft rubber rings are used as vacuum seals. A one inch copper pipe passes through the center of one end plate (hereafter called the base plate) for connection to the vacuum pump. Through the wall of this pipe there are several small tubes for counter filling and evacuating, electrical connections and vacuum gauge.

One inch above the base plate there is mounted a 1/8 inch brass disc to which are fastened the baffle system and the source holder. When all four counters are used a U shaped bracket holds the thread on which the course is deposited, vertically above the center of this plate. This may possibly lead to difficulty in some instances because of back-scattering from the thread. An alternative method which has been used in preliminary tests using only one counter is to mount a thin (.004 inch) brass sheet with a .010 inch slot directly over the center. The source is formed by evaporating a solution of RaD chloride on a thin collodion film so that the source covers an area 1 inch by 3\春天 inch. The film is then mounted behind the brass sheet so that electrons passing through the slot are focussed on the counter window. This method eliminates the back-scattering entirely and in addition gives a much greater intensity of Beta radiation.

The distance from source to counter window is 2.4 inches so that the electrons travel in paths whose radius is 1.2 inches (3.05 cm.). The baffles are cut to 1.212 inches radius, 1\% greater.
In making the baffles, advantage was taken of the fact that each pair form approximately a quadrant of a circle. For the inside baffle a solid cylinder 2 inches long was turned on the lathe to the exact diameter. It was then cut into quarters and the absorbing grooves cut in with a shaper. The outside baffles were made from a hollow cylinder turned to the exact inside diameter and handled the same way. These baffles are shown in Fig. 1(a).

The counters were made from four blocks of brass 1-1/2 inches long. Two parallel holes 5/8 inches diameter were drilled through each of these on centers 21/32 inch apart. The blocks were then trimmed down to a reasonable size with the shaper. Particular care was taken with the face in which the window was to be set. In the center line of this face only .030 inches of metal was left. The inside surfaces were then polished with emery paper and crocus cloth until quite smooth.

Next a narrow slot 3/4 inches long and .035 inches wide was cut through the front face of the first counter, parallel to the axis of the hole. This slot is covered with the collodion window. The preparation and mounting of these windows will be described later.

Glass caps, as shown in Fig. 1(b), are then sealed to the ends of the first hole and a .005 inch tungsten wire extended through the center. If the source being investigated emits no Gamma rays or only very weak ones, this counter may be mounted in position on the base plate and connections
FIGURE 1.

INTERNAL CONSTRUCTION OF THE SPECTROMETER
made to the filling system and scaling circuits. However, if the source emits strong Gamma rays, a rectangular hole \( \frac{1}{2} \) inch by \( \frac{3}{4} \) inch should be cut through the wall between the two holes, this slot forming the window for the second counter. Glass caps are then sealed to it and the center wire inserted. The two counters are then connected in a 'coincidence' circuit, i.e. a count is registered only if an electron traverses both counters. This usually happens only for electrons which are following the circular path through the baffles.

The use of this coincidence method on other spectrometers has resulted in a greatly reduced background count caused by Gamma rays from the source, scattered electrons, and cosmic rays.

The counters and their arrangement are shown in Fig. 1(c).

Because of the thinness of the collodion films it is necessary to evacuate the counters and the vacuum enclosure simultaneously, as a pressure differential greater than 10 cms of mercury will rupture the window. After the entire system is evacuated to \( 10^{-5} \) mm the counters are connected to the filling system by means of the stopcock ((d) Fig. 1) and filled to 5 cms pressure with a mixture of \( \frac{1}{7} \) alcohol and \( \frac{6}{7} \) argon.

The filling system is standard except that a ballast flask of about 4 liters capacity is included as the mixture of argon and alcohol slowly diffuses through the counter window. In this way runs of several hours could be made
without the characteristics of the counter changing appreciably.

The collodion windows are prepared as follows: Collodion is diluted with an equal volume of amyl acetate. Two drops of this solution are dropped in rapid succession into a pan of distilled water. The solution spreads in a thin film over a circular area about one foot in diameter of the surface of the water and dries in a few seconds. It can then be cut into sections by sawing a wire through it with a rapid up and down motion. The sections can be lifted out by means of a rectangular wire frame which is slid under a section of the film and lifted gently so that the film falls on both sides of the frame. Thus the film in its final state consists of two thicknesses of the original film. In this way a more uniform film, free from pinholes, is produced. It has been found that when the films dry, they are sometimes marked with straight lines. Care should be taken to select films that are clear as the marks seem to indicate breaks in one side of the film.

The film is mounted in the following way: The front face of the counter is covered with a thin coating of vacuum wax (Apiezon Q) so that the color of the brass shows through the wax. A thin sheet of brass .004 inches thick is cut to the size of the counter face and a slot cut in it .010 inches wide and $\frac{3}{4}$ inch long, so that this slot is approximately in the middle of the slot in the counter wall when the brass sheet is placed exactly on the flat face.
Then one side of this brass sheet is covered with a similar film of wax.

The counter is held firmly so that the flat face is horizontal and a film laid on the wax so that it breaks around the edges of the face. The brass sheet is placed on the film, wax side down, so that the two slots coincide. (A bright light shining through the slot in the counter is of great assistance in aligning, also later to check that no wax flows over the slots.) The brass sheet can be moved around to line up the slots without damaging the collodion film if no pressure is applied.

When the alignment is completed, the brass sheet is held firmly in place with a blunt object and a heated glass rod is run over the surface to melt the wax and weld the two inside surfaces together. Then the edges are covered with a small amount of wax. When the wax is thoroughly cool the counter is tested with a pressure differential of 7 to 10 cms of mercury. It is then installed in the spectrometer with the slot at the focus of the electron beam.

When the four counters and the source are installed the spectrometer is connected to the magnet and the vacuum system and it is ready for operation.

The entire spectrometer is made out of brass with the exception of the copper tubing and the outer baffles which were made of bronze as brass was not available in the correct size. In order to provide a surface of low atomic number and thus reduce the scattering of electrons as much
as possible all exposed surfaces were coated with a thin film of vacuum sealing wax.

B. THE MAGNET

The spectrometer requires a uniform magnetic field over a cylindrical volume 12 cms. in diameter and roughly 2 cms. deep. An arbitrary limit of one percent was set on the variation of the field over this region. Field strengths of 75 to 360 gauss were required to measure spectra from 5 Kev to 100 Kev (Hr 230 to 1100 gauss-cms).

Further restrictions were imposed by the limitations of the current control circuit. It was determined by experiment that the larger the load resistance the greater the total power available, but the less the accuracy of control. Thus a compromise had to be made and a resistance of approximately 12 ohms and a current of 10 amperes was chosen in order to give the maximum field of 360 gauss and the best possible control.

It is usual to use a pair of Helmholtz coils to provide a uniform magnetic field over a considerable volume, but it was felt that in this case, since the uniform field was required only over a thin disc shaped volume, that it could be provided by a coil or coils in one plane.

For a circular coil of radius \( a \) the field \( H_0 \) at the center is \( \frac{2\pi I}{a} \), where \( I \) is the current through the coil. Con-
sider the point P in the plane of the coil at a distance 
\( x < a \) from the center. Then 
\[ H_p = I \oint \frac{d\phi}{r}, \]
and 
\[ \frac{1}{r} = \frac{x \cos \phi - \sqrt{a^2 - x^2 \sin^2 \phi}}{x^2 - a^2} \]

Whence \[ H_p = \frac{I}{x^2 - a^2} \left[ \int_0^{2\pi} \sqrt{a^2 - x^2 \sin^2 \phi} \, d\phi - \int_0^{2\pi} x \cos \phi \, d\phi \right] \]
\[ = \frac{4Ia}{a^2 - x^2} \int_0^{\pi} \sqrt{1 - k^2 \sin^2 \phi} \, d\phi \quad \text{where} \quad k = \frac{x}{a} \]

Therefore \[ \frac{H_p}{H_0} = \frac{2a^2}{\pi (x^2 - a^2)} \int_0^{\pi} \sqrt{1 - k^2 \sin^2 \phi} \, d\phi \]

This is an elliptic integral and must be obtained from tables. A curve plotting \( H_p / H_0 \) against \( x/a \) is shown in Fig. 2.

By use of this curve it was determined that three coplanar coils, one of +14000 ampere turns of radius 17.5 cms, a second of -2700 ampere turns of radius 11 cms and a third of +120 ampere turns of radius 8.5 cms would give a field of approximately 360 gauss at their common center, with a maximum inhomogeneity of 0.28% over an area of radius 6 cm. (The minus sign on the second coil indicates that the current in this coil is in the opposite sense to the current in the other two coils.

These calculations, however, were for ideal coils and would not necessarily hold for coils of a finite cross-section such as is necessary to carry the current required.

As a maximum current of 10 amperes had been decided
upon, coils of 1400, 270, and 12 turns were needed. A preliminary calculation indicated that #14 wire was the smallest that would result in the required resistance of 12 ohms.

By trial and error calculations the coil arrangement shown in Fig. 3 was selected as giving a reasonably uniform field. There are two possible causes for the deviation of the field of this magnet from the field of the ideal magnet discussed above. The first is the finite width of the coils in the radial direction, the other is the finite thickness of the coils.

The finite width of the coils in the radial direction was taken into account in calculations by dividing the outer coil into 4 annular rings, the next into two annular rings and leaving the inner coil as one. For each of these annular rings, by use of the graph Fig. 2, the field at the center and at \( r = 1, 2, 3, 4, 5, 6 \) cms was calculated as a fraction of the field \( H_0 \) at the center of an ideal coil of 14000 ampere turns and 17.5 cms. The resultant field obtained by adding the individual fields algebraically for each value of \( r \) was equal to 70 \( \pm \) 1% of \( H_0 \).

It is evident because of the symmetry of the magnet that the finite thickness of the coils will have only a negligible effect on the direction of the field in the region considered. And further the uniformity of the field will not be changed over the small central region since in any plane through this region and perpendicular to the axis of the magnet the turns ratio of the coils is unchanged. The
FIGURE 3.
CONSTRUCTION OF THE MAGNET
only possible way that the thickness of the coils could influence the field would be to change its over-all value.

Consider a solenoidal coil of radius \( a \) with \( n \) turns per unit length and carrying a current \( i \). The field at the point \( P \) on its axis is given by

\[
H_P = 2\pi n i (\cos \phi_2 - \cos \phi_1)
\]

where \( \phi_1 \) and \( \phi_2 \) equal one half of the angles subtended at the point \( P \) by the ends of the solenoid. In the worst possible case for the magnet constructed \( \phi_1 = 78^\circ \), \( \phi_2 = 102^\circ \) which gives

\[
H_P = 0.832 \pi ni.
\]

The total current around the loop is

\[
2\pi a i \tan 12^\circ
\]

and if this were concentrated in a single turn the field \( H \) at the center would be

\[
H_i = 0.848 \pi ni.
\]

Thus

\[
\frac{H_P}{H_i} = \frac{0.832}{0.848} = 0.982.
\]

The finite thickness reduces the field by 1.8%. Therefore the field given by this magnet is equal to 69 ± 1% of the field \( H_0 \) at the center of an ideal coil of radius 17.5 cms and of 14000 ampere turns.

C. THE CURRENT CONTROL APPARATUS

The schematic and block diagrams of the current control apparatus are shown in Figs. 4 and 5 respectively. The system is essentially that used by Dr. L. G. Elliott in
FIGURE 4.

SCHEMATIC DIAGRAM OF CURRENT CONTROL CIRCUIT
FIGURE 5.

BLOCK DIAGRAM OF CURRENT CONTROL CIRCUIT
the National Research Council laboratories at Chalk River, with some modifications required by differences of equipment.

There are actually two control circuits in the apparatus with different frequency ranges. The 'D.C.' circuit will handle frequencies from zero to about 10 cycles per second; the 'A.C.' circuit will handle frequencies from 10 cycles per second to about 1000 cycles per second. Frequencies above this can be removed by means of suitable filter networks.

In the D.C. control circuit the voltage developed by the magnet current in passing through a small resistor (.08 ohms) is balanced against a voltage from a Rubicon potentiometer which in turn can be calibrated by a standard cell. The difference in these two voltages is converted into a 60 cycle square wave by means of a Brown converter. This is amplified about 100 db. then rectified by means of a 'phase sensitive detector' and the resultant D.C. voltage applied to the grids of the regulator tubes. The phase sensitive detector is merely a full wave detector biased by a 60 cycle voltage in order to ensure the proper polarity in the D.C. output voltage.

The regulator tubes are thirty-eight 6AS7 twin triodes on a separate chassis. The grids, plates, and cathodes, respectively of these tubes are connected in parallel with the exception of a grid 'stopper' of 1000 ohms in each individual grid. The filaments are connected in series, in two parallel banks of 19 tubes, across the 115 volt A.C.
18.

lines. The total rated plate current capacity of these tubes is roughly 10 amperes but they appear to work satisfactorily up to 18 amperes.

The A.C. control circuit consists of a normal negative feedback loop. A.C. fluctuations across the magnet are amplified by a 6AC7, then by a 6L6 and applied directly to the grids of the 6AS7's in the proper phase to reduce the fluctuations. To prevent oscillation due to phase shift the response of one stage is reduced greatly at high frequencies (greater than 1000 cycles per second). Fluctuations of higher frequency than this are eliminated to a great extent by a 500 mf condenser across the generator terminals. In addition it was found necessary to bypass each terminal of the generator to ground with .1 mf condensers connected directly to the brushes. Larger condensers than this reduced the commutator 'hash' even further but resulted in sporadic oscillations of the system.
III. RESULTS

A number of tests were carried out to check the uniformity of the magnetic field and to check the operation of the control circuit. In addition the operation of the counters was tested in various ways.

A. TESTS OF THE UNIFORMITY OF THE MAGNETIC FIELD

The uniformity of the field was checked experimentally in the following way: Two identical coils of 100 turns of #28 wire were wound on bakelite forms so that the inside diameter was 1 cm and the coil windings occupied a square of 0.5 cm side. The two coils were connected in series and to a ballistics galvanometer. With a measured current of 4 amperes through the magnet one coil was placed at the center of the magnet and the other at 'infinity'. The magnet circuit was broken and the deflection of the galvanometer observed. Then the coils were interchanged and the process repeated. The deflections differed by less than 0.5%.

Then one coil was fixed at the center of the magnet and the other, in opposite sense to the first was placed at a point in the region to be occupied by the spectrometer while the magnet current was interrupted. The galvanometer
deflections observed were thus proportional to the difference in the fields at the two points occupied by the coils, and by comparing the deflection to that due to one coil alone the percent variation of the field could be found. A large number of readings were taken for various positions of the second coil. The results are given by curves A in Fig. 6.

This shows that the maximum horizontal variation of the field was about 2% and that the field increased steadily as the distance from the center increased.

As the inner coil of 12 turns was very close to the spectrometer and thus had a fairly large effect on the field for the larger values of \( r \) a trial was made with this coil disconnected. The results are shown by the curves B in Fig. 6. The maximum variation over a cylindrical region 6 cms in radius and 2 cms thick is seen to be 1% which is the value originally specified. It was therefore decided to use the circuit with the inner coil disconnected for the present, but in the future further measurements will be conducted with different numbers of turns on the inner coil.

B. TESTS OF THE CURRENT CONTROL APPARATUS

An amplifier of about 90 db. gain was connected to an oscilloscope. Using a voltage divider an A.C. signal of .001 volts r.m.s. (.0028 volts peak to peak) was fed into the amplifier and a signal height of 3 inches was observed on the oscilloscope screen when the gain control was set at the 1/2 maximum gain point. The linearity of the gain control
FIGURE 6.

VARIATION OF MAGNETIC FIELD IN SPECTROMETER REGION
A. Inner Coil Connected  
B. Inner Coil Disconnected
was checked and no corrections were necessary to the dial setting. Thus at full gain a signal of .001 volts peak should give a deflection of 2.2 inches on the screen.

The amplifier input was then connected across the standard resistance in the magnet circuit. When the control circuit was in operation and magnet current flowing random pulses of a maximum height of 1 inch were observed. This is equivalent to a peak voltage of .0004 volts. These surges were very narrow, less than 100 micro-seconds, and the frequency was about 100 times per second.

No apparent change in the amplitude of these surges was noticed between magnet currents of 50 m.a. to 10 amperes so long as control was maintained. At less than 50 m.a. the system started to oscillate because of the effect of the small condensers connecting the generator brushes to ground. When these were disconnected the system did not oscillate for any value of the current, but the voltage surges mentioned above increased in amplitude by a factor of 2 or 3. It is evident that these random surges are due to commutator 'hash'.

A current of 50 m.a. develops .004 volts across the standard resistance while 10 amperes develops .8 volts. Thus the pulses varied from 1 part in 10 to 1 part in 2000. Their maximum ratio for currents to be used in the magnet is about 1 part in 50. Further it is thought that the actual magnet current does not follow the form of the voltage across the standard resistance since the magnet has approximately 1 Henry inductance. The high frequency components of the
voltage are probably short-circuited across the magnet by the inter-turn capacity.

As far as D.C. or low frequency fluctuations are concerned none of greater than .1 inches were observed on the oscilloscope screen and at low currents they were not detectable. They certainly could have been observed if as great as .05 inches. Thus the D.C. control is accurate to at least 1 part in 10,000 over the entire usable current range.

**C. TESTS OF THE SPECTROMETER**

The entire apparatus was assembled and mounted on a small table so that the magnetic field of the coil was parallel to the earth's magnetic field. Connections were then made to the vacuum pump and to the counter filling system. The apparatus was found to be reasonably vacuum tight, but special care was required in the positioning of the rubber sealing rings in order to ensure a tight joint.

For preliminary tests only one counter and one set of baffles were installed as fairly large source strengths were available. A test of the counter was made with the window completely sealed with a brass plate. A source emitting strong gamma rays was used and the counter when filled appeared to operate efficiently, with a plateau of approximately 75 volts starting at about 850 volts.

A source of Radium D was then put in the spectrometer using the alternative method described in II A. The counter, now with a collodion window installed, was mounted
in the spectrometer and aligned with the baffle system, and connections made to the high voltage power supply and to the scaling circuits.

A great deal of difficulty was then encountered. The mixture of argon and alcohol used for filling the counters appeared to leak through the window even though it was airtight as far as could be ascertained. On several occasions 5 cms of air was allowed to enter the counter without changing the degree of vacuum in the spectrometer, yet when this was pumped out and the counter filled with 5 cms of argon and alcohol mixture the vacuum gauge immediately indicated a leak.

These leaks were so large that it was impossible to maintain the 5 cms pressure in the counter even with the ballast flask attached to the filling system.

As a result when the voltage was applied to the counter, it went into almost continuous discharge with the possible exception of a few short intervals when it appeared to be operating normally.

Further attempts were carried out to make the counter operate successfully. A slightly thicker window was installed and extreme care taken to ensure that the pressure differential across the window was kept to a very low level at all times. This was done by 'throttling' the vacuum pump with a clamp on the rubber hose connection.

None of these attempts have as yet been successful and consequently no readings of the Beta-ray spectrum of
Radium D have been taken. It is felt, however, that successful operation of the apparatus depends only on the development of the proper technique of dealing with the colloidion films. At the time of writing, counters have been prepared with apparently leak proof windows and work is continuing.
IV. CONCLUSION

While the spectrometer as a unit has not yet been tested successfully, the principles involved are sound, and as it now stands the apparatus should give satisfactory measurements of low energy Beta-ray spectra, once the proper techniques of mounting the collodion windows have been developed and mastered.

However, certain improvements and modifications will increase the flexibility of the spectrometer while others will make it easier of operation.

A higher voltage magnet power supply would enable the range of the spectrometer to be extended almost to 200 Kev. The limit of course depends on the temperature rise of the copper in the magnet but water cooling coils could readily be attached.

It will probably be necessary to develop a simpler method of attaching the collodion windows to the counters in order to reduce the danger of breaking the films while setting up the counter and at the same time making the techniques involved less painstaking and delicate.

The uniformity of the magnetic field can quite readily be improved to almost any desired degree of accuracy by changing the turns ratio of the coils. It may also be
necessary to clamp the sides of the magnet together more firmly as a slight warping developed when the coils were being wound.

The development of this spectrometer is being continued and when it is successfully operated it should prove to be a valuable tool for the investigation of low energy Beta- and Gamm-ray spectra.
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PLATE I.

THE SPECTROMETER PARTIALLY ASSEMBLED
PLATE II.

THE MAGNET AND FIELD TESTING COILS
PLATE III.

THE CURRENT CONTROL PANEL
PLATE IV.
THE MAGNET AND SPECTROMETER ASSEMBLED
PLATE V.

THE 6AS7 REGULATOR CHASSIS