# THE GAMMA-RAYS OF RADIUM

by

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## ACKNOWLEDGEMENT

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## ABSTRACT

The thin-lens beta-ray spectrometer is described, together with its associated equipment. The energies of gamma-rays, emitted by Radium in equilibrium with its disintegration products have been determined by measuring, in such a spectrometer, the energies of photoelectrons ejected from lead. These energies agree reasonably well with those reported by Ellis and Skinner, although several values reported by Alichanov and Latyshev have not been found. The energy calculations were based on a calibration using the F line of Thorium B ($H\rho$ = 1385.6 gauss-cm.). An indication was found of a gamma energy not previously reported.

# THE GAMMA-RAYS OF RADIUM

## I. INTRODUCTION

Previous measurements of Radium gamma-ray energies have been made by several investigators. Ellis and Skinner[1], measuring internal conversion and photoelectric line energies in a $\pi$-type spectrometer reported twenty-one gamma-rays of Radium B, C and D. Alichanov and Latyshev[2] measured the energies of positrons formed by pair-production in lead with a $\pi$-type spectrometer, and from these measurements reported eleven gamma-rays of Radium C, of energies greater than 2 $m_oc^2$ (i.e. 1.02 Mev). Tsien[3], using selective absorption and crystal diffraction in the range 25-50 Kev, and the cloud chamber in the range 7-25 Kev reported six gamma-rays of Radium D. While in the high energy

(1) C.D. Ellis and H.W.B. Skinner, Proc.Roy.Soc., 105A, 165 (1924).

(2) A. Alichanov and G. Latyshev, C.R.Acad.Sci. (U.R.S.S.), 20, 429 (1938).

(3) S.T. Tsien, Phys.Rev., 69, 38 (1946).

region at least, a comparison of results shows fair agreement, there are some discrepancies and it seemed advisable to repeat this work with the thin-lens spectrometer at our disposal.

# II. EXPERIMENTAL METHOD

## 1. SPECTROMETER TYPES

The negative beta-rays from radioactive nuclei consist of electrons whose energy varies continuously from a certain maximum value down to zero. Gamma-rays may also be emitted from such nuclei, and since they represent transitions between excited nuclear energy states, they possess discrete energies. To observe beta-ray distributions, beta spectrometers of various designs have been developed. Under the proper conditions the beta spectrometer may be used equally well to investigate gamma-ray energies, either by measuring the energies of photoelectrons expelled by these gamma-rays from thin high atomic number lamina, by measuring Compton recoil electron distributions ejected from thick absorbers of low atomic number, or by measuring the energies of positrons or negatrons created by pair production in high atomic number absorbers.

Four types of instruments are in general use.

(a) The Magnetic Semicircular Focussing Spectrometer ($\pi$-type), shown in Figure 1, was devised by Danysz[4] in 1912. It was later improved by Robinson and Rutherford[5]

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[4] J. Danysz, Le Radium, 9, 1 (1912); 10, 4 (1913).
[5] H. Robinson and E. Rutherford, Phil.Mag., 26, 717 (1913).

and has since been very widely used. A uniform magnetic field is applied perpendicular to the plane of the figure. Beta-rays in a small momentum interval describe circles of approximately equal radii in the field and are therefore focussed at the same point on the photographic plate. A Geiger tube may be used in place of the photographic plate, in conjunction with a magnetic field which can be varied.

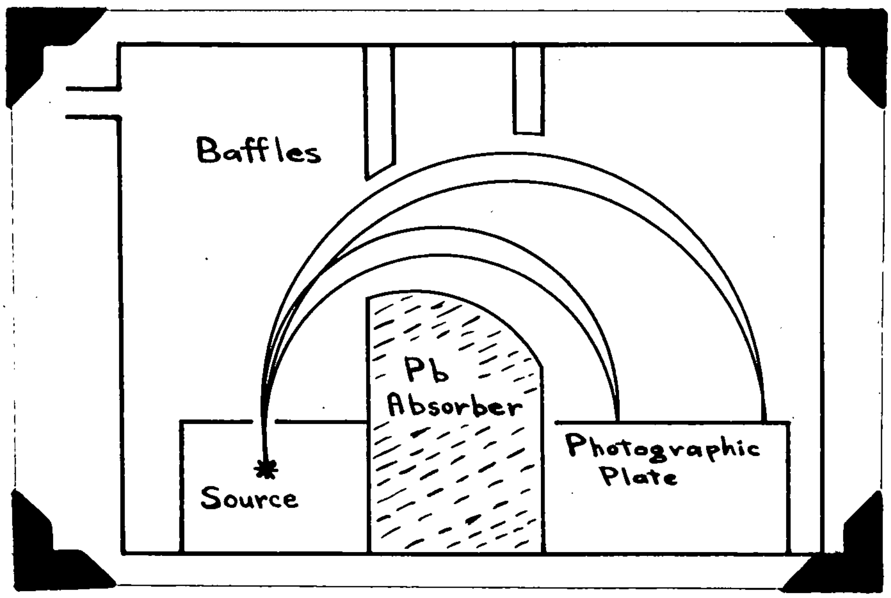


Figure 1.

(b) The Electrostatic Focussing Spectrometer, shown in Figure 2, was suggested by Hughes and Rojansky[6]. This instrument uses a radial, inverse first-power, electrostatic field to focus a bundle of electrons of the same energy in a manner similar to that of a magnetic field. An angle of deviation of 127° 17' is found to give the correct focussing condition. The instrument is particularly useful for low

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[6] A.L. Hughes and V. Rojansky, Phys.Rev., 34, 284 (1925).

energy particles, and has been used successfully by Backus[7] to measure the low energy negatron distribution of $Cu^{64}$.

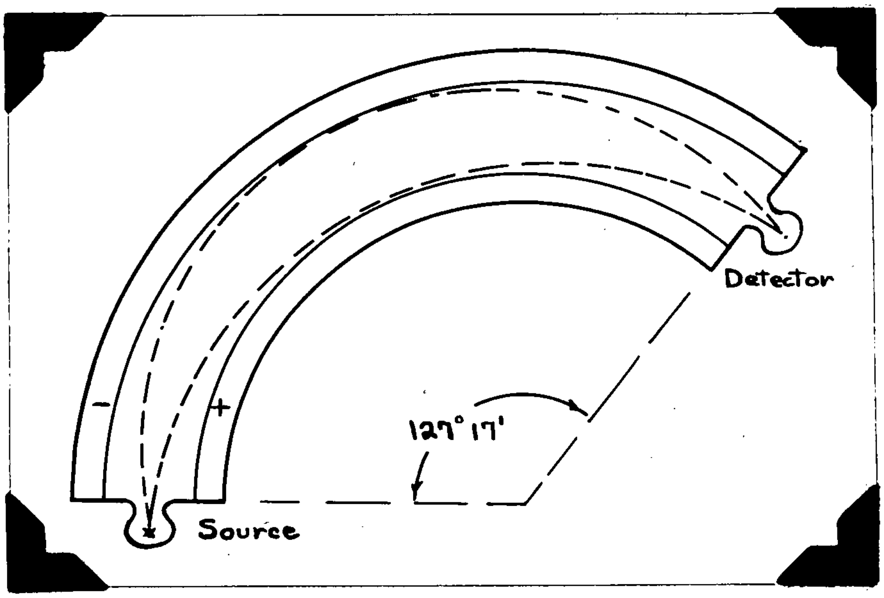


Figure 2.

(c) The Electron Lens type of spectrometer is shown in Figure 3.

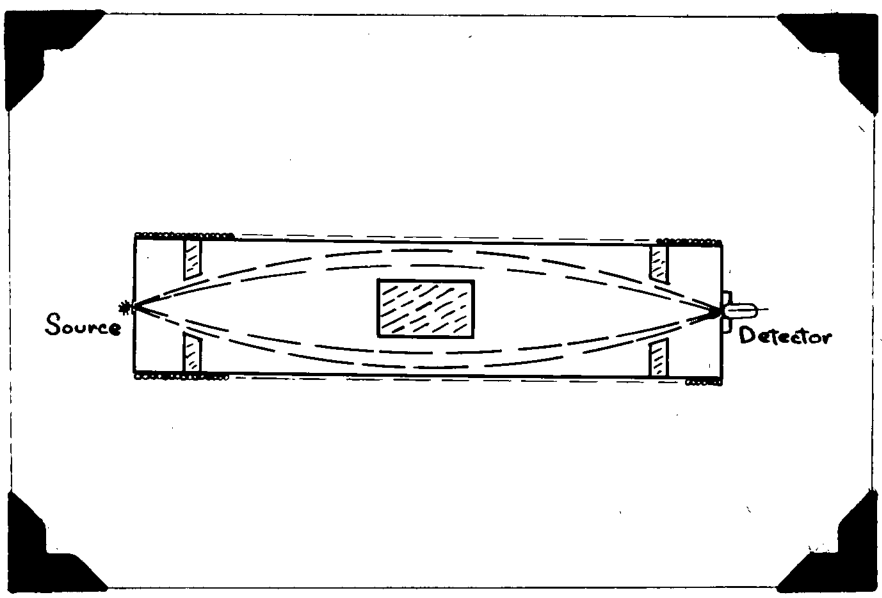


Figure 3.

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[7] J. Backus, Phys.Rev., 68, 59 (1945).

This arrangement was first used by Tricker[8] in 1924. The evacuated cylinder is surrounded for its entire length by a solenoidal wound conductor. For a given current through the solenoid, electrons of a certain energy will be focussed on the detector.

(d) A variation of this type of instrument is the thin-lens spectrometer, as introduced by Deutsch, Elliott and Evans[9]. This is the type of spectrometer used in the present study. It is described in detail in the sections which follow.

## 2. THE THIN-LENS SPECTROMETER

The thin-lens spectrometer is shown in section in Figure 4 and in a photograph in Plate I. It consists essentially of an evacuated cylindrical brass tube 8 inches in diameter and 40 inches long, surrounded at its centre by a short magnet coil of heavy wire. The coil is water cooled in order to reduce temperature fluctuations. The tube contains five lead baffles which perform several functions. Baffle A transmits a conical beam of electrons from the radiator into the focussing field of the magnet. Baffle B prevents high-energy radiation from passing directly from source to counter. C is a masking baffle and together with D and E serves to absorb much of the scattered radiation which might otherwise reach the counter and thus increase the

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(8) R.A. Tricker, Proc.Camb.Phil.Soc., 22, 454 (1924).
(9) M. Deutsch, L. Elliott and R. Evans, Rev.Sci.Instr., 15, 7 (1944).

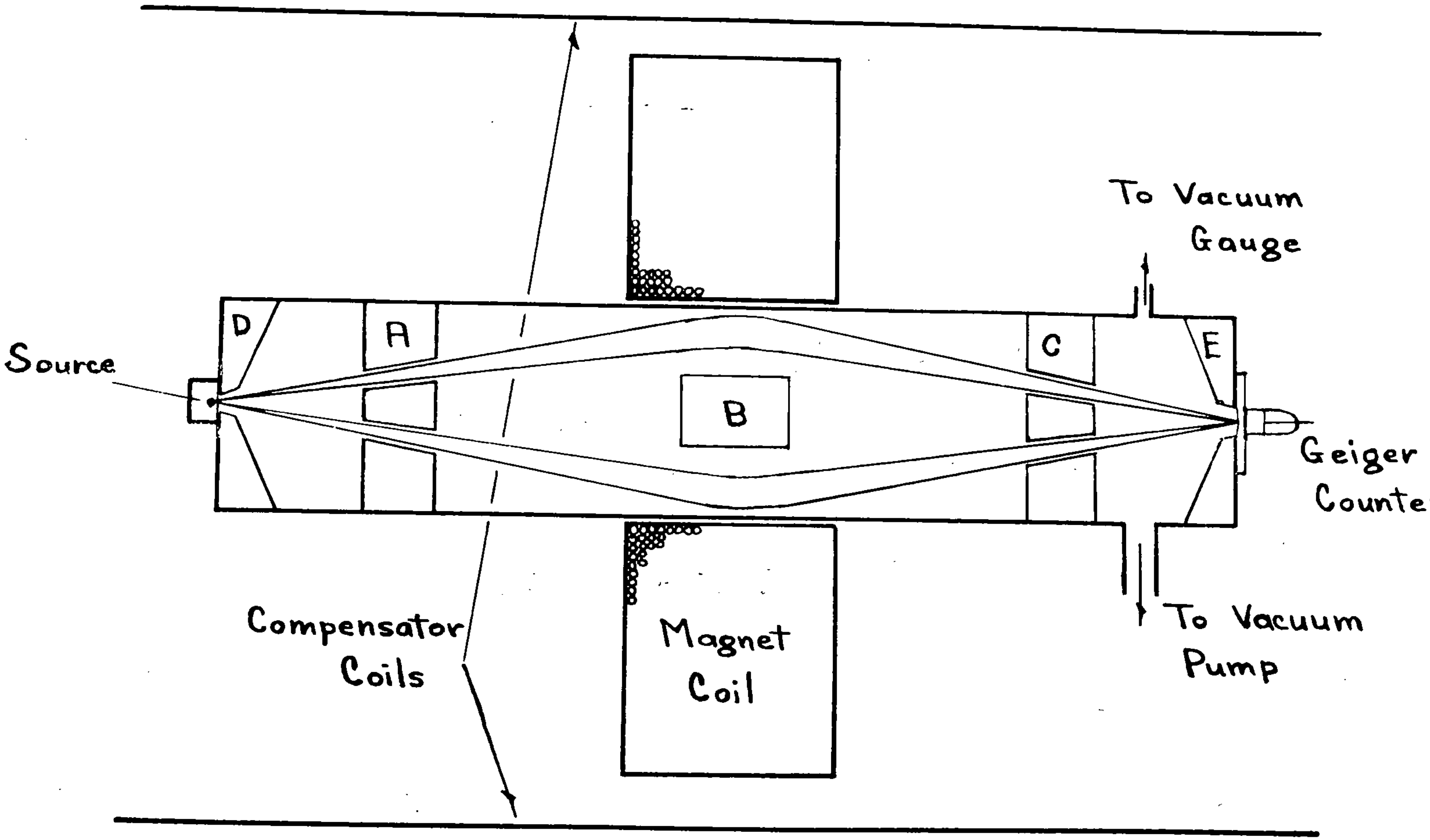
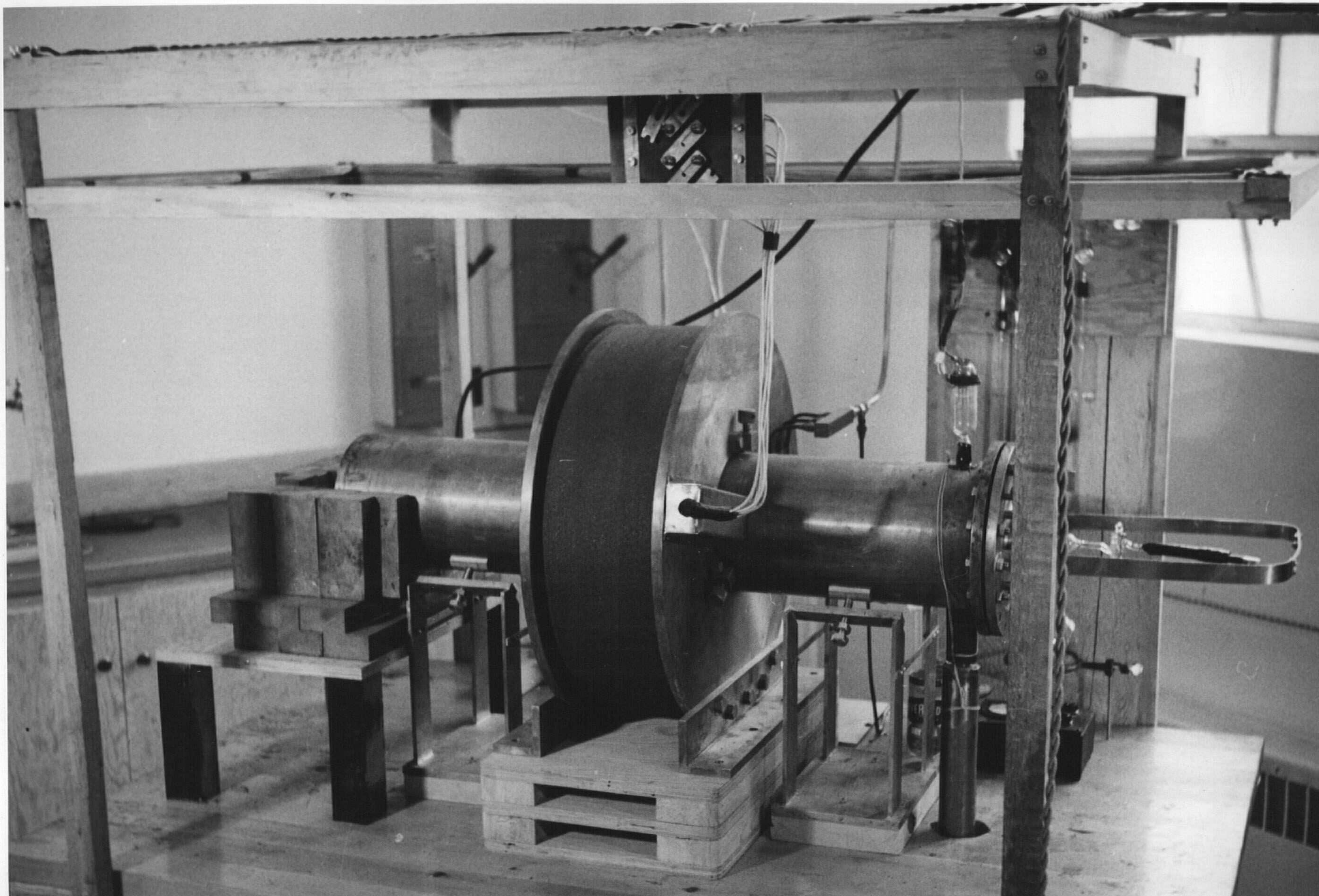

To Vacuum Gauge
D
A
B
C
E
Source
Geiger Counter
Compensator Coils
Magnet Coil
To Vacuum Pump

Figure 4.



normal background. A Cenco Megavac pump is used to evacuate the system, with an oil diffusion pump included for lower pressures when necessary. The vacuum indicator is a thermocouple gauge.

The cone of electrons passing through the defining baffle A is focussed by the action of the magnetic field of the coil. For a given coil current, electrons of the appropriate energy will pass through baffle C, and be focussed on the "window" of the Geiger counter. Electrons of other energies would, in the absence of baffles, be focussed at other points along the axis of the spectrometer tube. Since the coil contains no iron, the field and hence the momentum of the focussed electrons will be linear with current.

## 3. SOURCE ARRANGEMENT

Figure 5 shows the source arrangement used in this study.

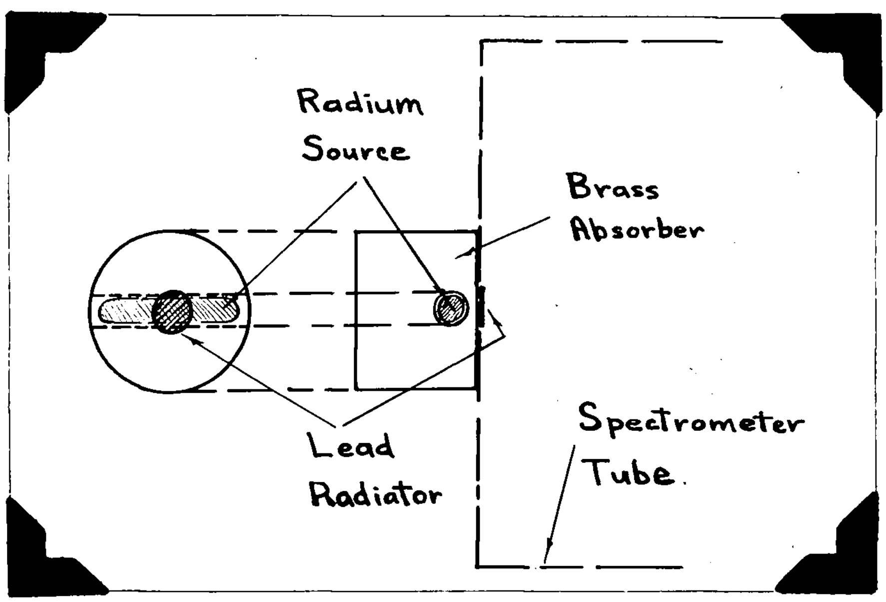



Figure 5.

The Radium used was enclosed in a silver capsule 1 inch long and 1/8 inch in diameter. This was placed in a small hole drilled through a solid brass cylinder as shown. The cylinder was sealed to the end of the spectrometer tube. On the end of the cylinder facing into the spectrometer was cemented a circular lamina of lead, 3 millimetres in diameter and 0.044 millimetres thick, of surface density 50 milligrams per square centimetre. This will be referred to as the lead radiator. The thickness of brass between the Radium and the lead was made sufficient to absorb all the primary beta-rays from the source, calculation for this minimum thickness being made on the basis of the well known Feather formula[10],

$$R(\text{gms/cm}^2) = 0.543\,E\,(\text{Mev}) - 0.16.$$

Gamma-rays emitted from the source pass through the brass and eject photoelectrons from the lead. In addition, Compton electrons in a continuous distribution are ejected from the brass absorber. Both photoelectrons and Compton electrons are detected and counted in the spectrometer with the result that a plot of electron intensity versus electron momentum is a composite curve, showing a series of mono-energetic photoelectric peaks superimposed upon the continuous Compton distribution. In order to correct the curve for Compton background, the lead radiator is removed and a background curve is plotted over the same momentum range. This curve, sometimes normalized to fit the composite curve, is

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(10) J.M. Cork, "Radioactivity and Nuclear Physics", (Van Nostrand) P. 121.

subtracted from the latter, and the resulting plot gives the line spectrum due to photoelectrons ejected by gamma-rays from the lead.

## 4. THE GEIGER COUNTER

The counter, shown in Figure 6, is of the bell type,

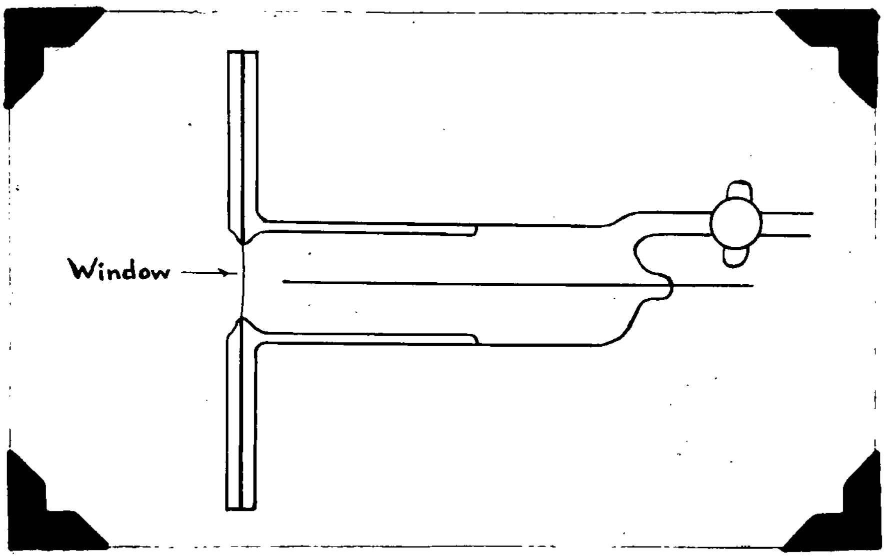



Figure 6.

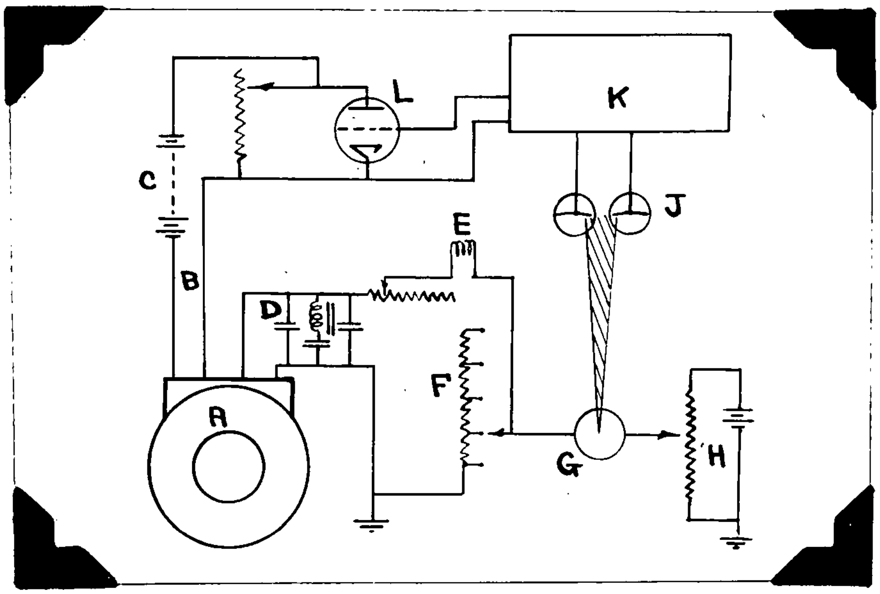
having a diameter of 0.75 inches, and a central anode of 0.005 inch tungsten wire. It is filled with a mixture of Argon and Ethyl Alcohol vapor, 9.3 cm. (Hg) of Argon with 0.7 cm. of Alcohol vapor having been found to give a good pulse shape and a usable plateau. A sample plateau rises from 750 counts per minute at 975 volts to 1000 counts per minute at 1070 volts, a rate of increase of 0.3 percent in counts per minute per volt. With a lead shield around the counter, normal background (with source in place, no current through the magnet coil) is of the order of 60 counts per minute. A mica window of surface density 0.89 milligrams per square centimetre was used. This window was found to absorb all energies below 50 Kev, and this automatically sets a lower limit to the energies which may be measured. Considerable care must be exercised in order to avoid subjecting such a thin window to differential pressures much greater than 10 centimeters of mercury, since its strength is not great. A brass mask with a central circular hole in it is fitted over the counter window. The diameter of the hole is made about 1 millimetre greater than the diameter of the source. The mask is intended to improve the resolving power of the spectrometer by eliminating from the counter electrons not properly focussed. A removable flange on the counter permits replacement of the window and easy sealing of the counter to the spectrometer tube. Pulses are counted by a scale-of-64 scaling unit which actuates a mechanical register.

## 5. COUNTER POWER SUPPLY

The counter power supply consists of a high voltage battery pack with a switching arrangement which gives steps of 15 volts over the range from 840 to 1400 volts. A stable supply voltage is a necessity since changes in voltage will cause changes in counting rate and will thus distort the results. In the absence of an accurate voltmeter, reproducibility of points on a curve is the most reliable test of the supply voltage.

## 6. MAGNET CURRENT SUPPLY

A D.C. generator supplies current for the magnet coil. This current is regulated to within 1 part in 1000 by means of a photocell control circuit, shown in Figure 7.




A - D. C. Generator
B - Generator Field Circuit
C - Generator Field Supply
D - Load Circuit Filter
E - Magnet Coil
F - Standard Resistance
G - Galvanometer
H - Potentiometer
J - Photocells
K - Amplifier
L - 8 Parallel 6L6 Tubes

Figure 7.

The operation of the regulator is as follows. The potentiometer, used as a reference voltage, is standardized by means of a Weston Standard cell. The voltage across a standard resistance in the load circuit of the generator is then balanced by the required potentiometer voltage. When the system is in balance the galvanometer reads zero current, and the galvanometer light beam takes up a position midway between the two photocells. This is the desired operating condition.

In this condition, the two photocell output voltages are balanced against each other and no signal voltage reaches the next stage of the amplifier. If now the magnet current begins to change, the voltage across the standard resistance also begins to change, and this deflects the galvanometer light. The resulting off-balance photocell signal is amplified and applied to the grids of the 6L6 tubes in such a way that the generator field current is altered to compensate for the original change in magnet current. As shown in the diagram, the generator field is separately excited, from batteries of large current capacity. Such an arrangement adds to the stability of the regulator. Because of the relatively slow response of the galvanometer and the long time-constant of the generator field, this system is useful in controlling only slow variations of current (greater than 0.5 seconds). Hence considerable extra filtering on the generator output as well as on the magnet load was found necessary.

The importance of a high degree of regulation for the magnet current cannot be too firmly stressed. A varying current has the effect of reducing peak height and increasing peak width, thereby reducing both the resolving power and the sensitivity of the spectrometer. Since many of the gamma-rays are only weakly converted, their resultant photoelectric peaks are very small, and an instrument with poor sensitivity will not detect them.

At the same time it must be admitted that this control circuit which holds the current constant to 0.1 percent is better than is actually needed when we consider the relatively low resolution of the spectrometer.

## 7. EARTH'S FIELD COMPENSATOR

Two rectangular coils connected as Helmholtz coils were arranged in horizontal planes, one above and one below the spectrometer tube and placed symmetrically with respect to its axis. Their function is to compensate for the effect of the vertical component of the earth's field, which could cause defocussing of beta particles over their long path. Current for the coils is supplied from batteries and must be held as nearly constant as possible. Further remarks regarding the importance of the compensator will be made in the following section.

## 8. ALIGNMENT

Four major factors must be considered in the alignment of the thin-lens spectrometer.

(a) The spectrometer tube axis should lie in the plane of the earth's magnetic meridian. The earth's field strength (vertical component) and direction (horizontal component) are plotted over the area available in the laboratory. An optimum position is then chosen for the spectrometer, taking into account the rate of variation of vertical field strength with distance along the tube axis.

(b) The current through the compensator coils must be adjusted to counteract the effect of the vertical component of the earth's field. If this field strength is not sensibly constant throughout the length of the spectrometer tube, then obviously some compromise must be made in the current value chosen for the coils. A plot of the resultant field, with compensating coils in operation at an optimum current is shown in Figure 8.

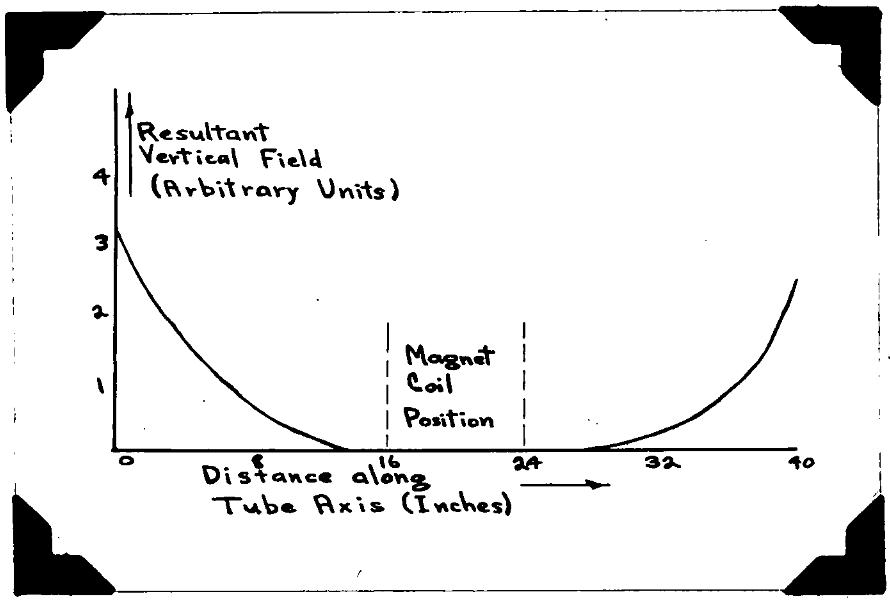



Figure 8.

(c) The spectrometer tube was placed symmetrically with respect to the field of the magnet. First the tube was aligned visually so that its axis and centre point coincided as nearly as possible with those of the magnet coil. Then as a final adjustment, sample counts were taken with a source in place and a constant current through the magnet, for different positions of the tube. The position of each end of the tube was changed (vertically or horizontally only) in turn, and the final position chosen was that for which the counting rate was a maximum. The tube was then clamped in this position.

(d) The chosen value of compensator coil current should give good peak shape, which implies maximum peak height combined with minimum width and least distortion. As a final criterion for this current value, a strong photoelectron peak was located in the spectrum of the Radium source, and this peak was plotted using several different values of compensator current. A sample plot is shown in Figure 9, with the various compensator currents indicated thereon. It is seen from this that little doubt arises as to the required compensator current value. Such a current value is then used in the earth's field compensator coils for all subsequent work.

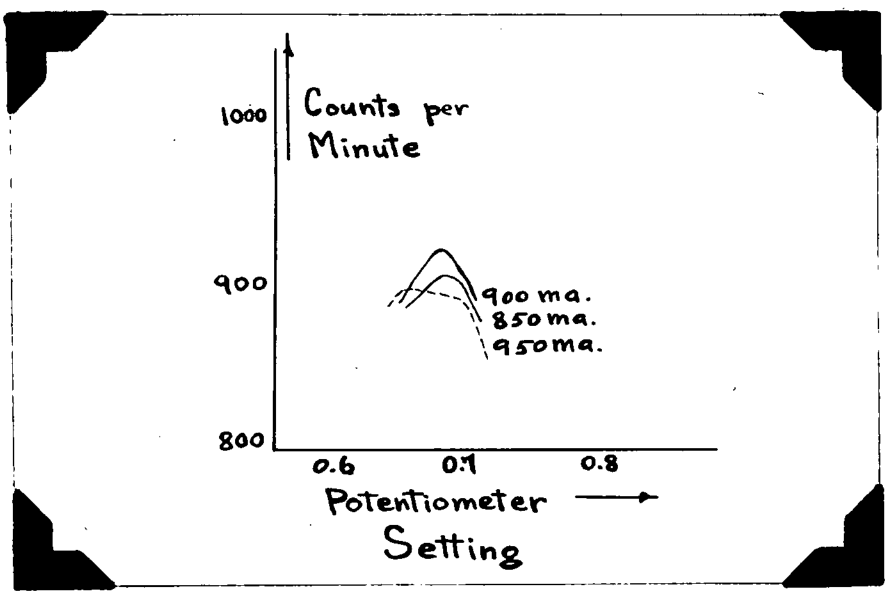



Figure 9.

## 9. RESOLUTION

The resolving power of the instrument, which is defined as the peak width (expressed as a percentage) at half-maximum intensity, was found to be approximately 4 percent.

## 10. CALIBRATION

As was mentioned previously, the field of the magnet is linear with current, because of the absence of iron. Therefore only single-point calibration is required. The instrument was calibrated with the very strong (conversion) F line of Thorium B ($H\rho$ = 1385.6 gauss-cm)[11]. Using a very thin source in order to obtain as sharp a line as possible, and mounted on a thin sheet of mica to reduce back-scattering, the Thorium F line was plotted as shown in Figure 10. The Thorium source arrangement is also shown in the same figure. The potentiometer reading which corresponds to the $H\rho$ value of 1385.6 gauss-cms for the F line was found to be 0.228 volts. From this all the required $H\rho$ values are found.

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(11) C.D. Ellis, Proc.Roy.Soc., 138, 318 (1932), and K.C. Wang, Zeits.f.Phys., 87, 633 (1934).

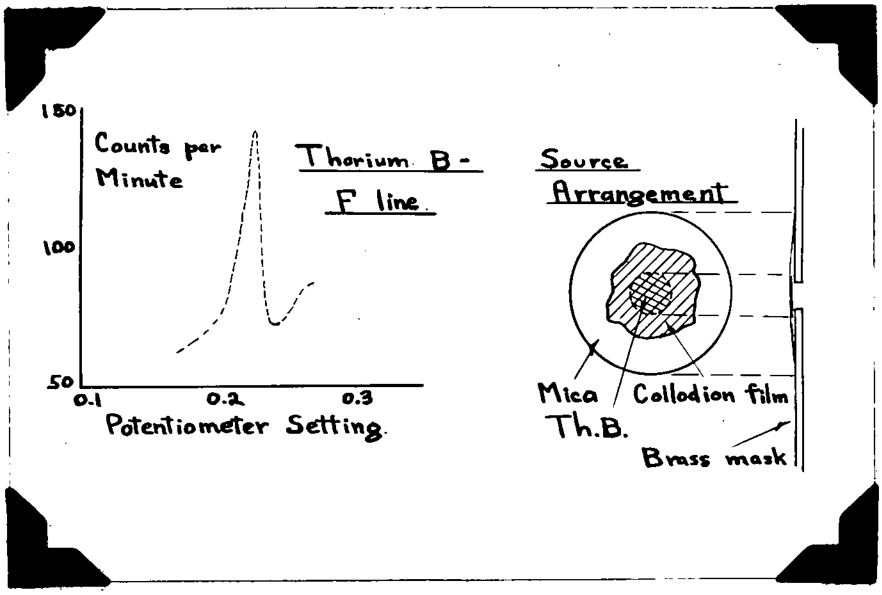


Figure 10.

## 11. CALCULATION OF GAMMA-RAY ENERGIES

Using the well known equation

$$H\rho = \frac{10^4}{3}\sqrt{T(T + 1.02)}$$

where $H\rho$ represents the electron momentum in gauss-cm, and T the kinetic energy in Mev, the latter can be determined.

For a photoelectron peak,

$$h\nu \text{ (gamma-ray energy)} = T + E_b$$

where $E_b$ is the electron binding energy, and hence the energy of the gamma-ray can be found.

For lead, the value of $E_b$ for the K shell is 87.6 Kev[12], and for the L shell 15.8 Kev, their difference being 71.8 Kev.

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[12] J.M. Cork, loc.cit. p. 301.

# III. EXPERIMENTAL RESULTS

## 1. REDUCTION OF PRIMARY BETA BACKGROUND

An attempt was made to improve the sensitivity of the spectrometer in the following way. The brass absorber over the source has one function only, and that is to prevent the intense primary beta radiation from the source from arriving at the counter. This it does, but a Compton background is introduced in its place, though much less intense than the primary beta radiation it replaces. Nevertheless this Compton background still imposes a limit upon the photoelectron line intensity that can be observed because of the unavoidable statistical fluctuations of intensity of both background and photoelectric peaks.

Therefore an attempt was made to remove the primary beta radiation by replacing the brass absorber with a strong magnetic field, which could not of course give rise to Compton secondaries. The gamma-rays would be unaffected and this beam would then eject photoelectrons from the lead with little or no background. The experimental arrangement is shown in Figure 11.

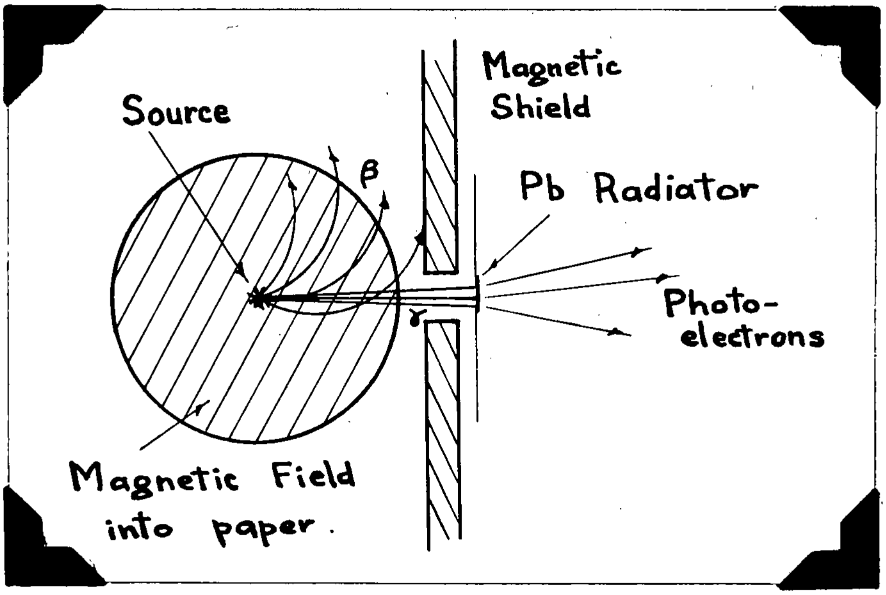


Figure 11.

The difficulties proved to be as follows:

(a) With a primary beta energy of the order of 2.5 Mev, strength of fields available about 7000 gauss, and the geometry employed, minimum source-to-radiator distances of the order of 1.5 centimetres were required to divert the most energetic beta-rays from the spectrometer beam.

(b) Such a source-to-radiator distance proved to be so great that with the source available (10 millicuries) the photoelectron peaks were too small to detect, even without any appreciable background.

(c) It was necessary to have the deflecting magnetic field cut off sharply short of the lead radiator in order to avoid interfering with the focussing properties of the spectrometer magnet.

Various arrangements of source, field and radiator were tested. Because of the difficulties noted above, and the limitations imposed by the geometry of the source, which were unavoidable as this was the only source available, this method was not found to be feasible. Indications are, however, that it would be useful for a source of greater intensity, and perhaps even with a source of the strength used but with a more suitable shape. As was noted before, the source used was not a point source but a cylinder 1 inch long and 1/8 inch thick, and this shape complicated the problem considerably.

## 2. THE RADIUM GAMMA-RAY SPECTRUM

A graph of the photoelectron peaks over the entire momentum range covered in this study is shown in Figure 12. The upper curve is the composite curve referred to earlier. The dotted line indicates the Compton background, and the lowest curve represents the difference between the other two. The horizontal scale is such that the momentum interval at any point is a constant percentage of the total momentum at that point. (Electron momentum is linearly proportional to the Potentiometer voltage shown.)

## 3. STATISTICAL ACCURACY

The average intensity per point (on peak outline) is approximately 640 counts per minute. For the average counting time of 12 minutes this gives a total count per point of about 7700. On the Compton background curve the average intensity per point is about 600 counts per minute,

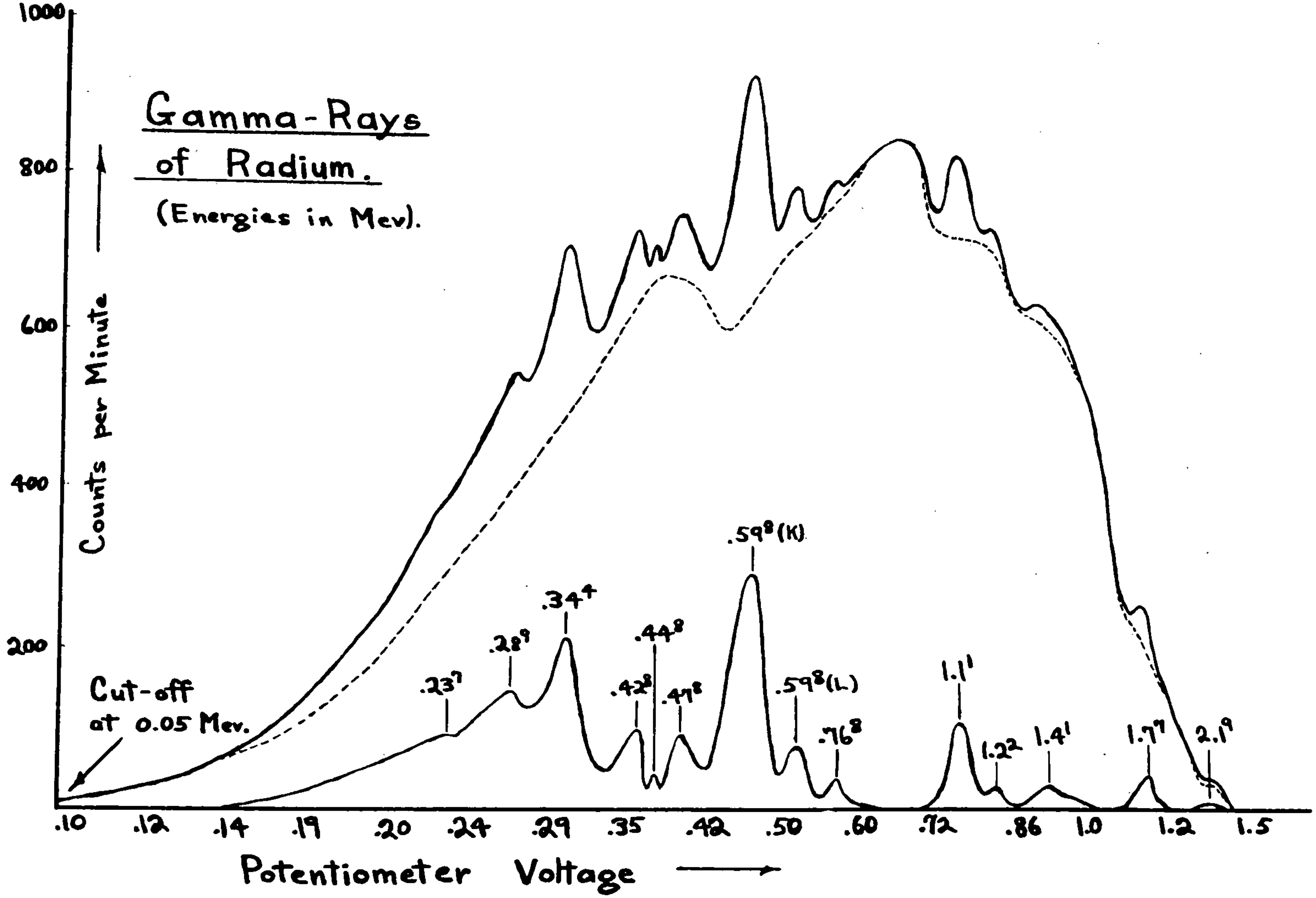
Gamma-Rays of Radium.
(Energies in Mev).
Counts per Minute
1000
800
600
400
200
Cut-off at 0.05 Mev.
.23⁷
.28⁹
.34⁴
.42⁸
.44⁸
.47⁸
.59⁸(K)
.59⁸(L)
.76⁸
1.1¹
1.2²
1.4¹
1.7⁷
2.1⁹
.10
.12
.14
.19
.20
.24
.29
.35
.42
.50
.60
.72
.86
1.0
1.2
1.5
Potentiometer Voltage

Figure 12.

which leads to a total count of 3600, for the counting time of 6 minutes. The statistical accuracies of these two measurements are 1.1 and 1.7 percent respectively. The resultant statistical accuracy u of the points which give the peak outline is given by the formula

$$u = \sqrt{x^2 + y^2}$$

where x and y are the errors in each of the two independent measurements. This leads to an average statistical accuracy of ± 2 percent.

## 4. ERROR IN ENERGY DETERMINATION

The accuracy of the energy determination is of course an important factor. The error in potentiometer standardization is small enough to be neglected. The probable maximum error in determining the "calibration point" is estimated to be less than 1 percent. Similarly the maximum error in reading the highest point of a given photoelectron line is estimated to be also less than 1 percent. These are considered to be the major sources of error. They lead to a probable maximum error in calculated gamma-ray energy of ± 1.5 percent. An indication of the accuracy of the experiment is given by the binding energy difference which was found between the K and L conversion lines of the 0.598 Mev gamma-ray. This difference was found to be 73 Kev, a value which agrees reasonably well with the quoted value of 71.8 Kev, noted earlier.

## 5. COMPARATIVE RESULTS

Table 1 shows a comparison between the values found in this study and those of earlier investigators.

TABLE 1

| Ellis and Skinner | Alichanov and Latyshev | | Mann and Ozeroff | |
|---|---|---|---|---|
| Gamma-ray Energy * | Gamma-ray Energy | Relative Intensity | Gamma-ray Energy | Relative Intensity |
| .0472 | | | | |
| .0536 | | | | |
| .0589 | | | | |
| .243 | | | $.23^{7}$ | 0.6** |
| .260 | | | | |
| .275 | | | | |
| .297 | | | $.28^{9}$ | 11** |
| .332 | | | | |
| .354 | | | $.34^{4}$ | 28** |
| .429 | | | $.42^{8}$ | 6 |
| | | | $.44^{8}$ | 2.2 |
| .471 | | | $.47^{8}$ | 11 |
| .503 | | | | |
| .612 | | | $.59^{8}$ | 55 |
| .773 | | | $.76^{8}$ | 11 |
| .941 | | | | |
| 1.13 | | | $1.1^{1}$ | 78 |
| 1.248 | 1.21 | 23 | $1.2^{2}$ | 33 |
| | 1.29 | 18 | | |
| 1.39 | 1.39 | 49 | $1.4^{0}$ | 22 |
| 1.43 | | | | |
| | 1.52 | 29 | | |
| | 1.62 | 22 | | |
| | 1.69 | 17 | | |
| 1.78 | 1.75 | 100 | $1.7^{7}$ | 100 |
| | 1.82 | 17 | | |
| | 2.09 | 15 | | |
| 2.22 | 2.20 | 41 | $2.1^{9}$ | 22 |
| | 2.42 | 21 | (2.4) | - |

* Relative intensities not given.

** Not corrected for photoelectric cross-section.

Relative intensities of the gamma-rays are included also. The intensities shown here have been corrected to take into account the decreasing cross-section for the photoelectric effect with increasing energy, using published[13] cross-section curves.

[13] C.D. Coryell, M. Deutsch, R.D. Evans, W.J. Ozeroff et al - The Science and Engineering of Nuclear Power, (Addison-Wesley) p. 40.

## IV. CONCLUSION

An examination of the graph in Figure 12 shows that in the lower energy portion of the spectrum the photoelectron peaks are very prominent, while in the high energy section they become very weak. This condition is due in part to the fact that the photoelectric cross-section decreases very rapidly with increasing photon energy. For gamma-rays in lead, the absorption coefficient decreases from a value of 1.6 $cm^{-1}$ at an energy of 0.4 Mev to 0.03 $cm^{-1}$ at 2.5 Mev. This means that we must expect the photoelectron peaks to become weaker and weaker as we pass to higher gamma energies.

From the Compton background end-point at the upper limit we can find an approximate value for the energy of the gamma-ray which is responsible for the Compton background in that region, but which is apparently too weak to show as a photoelectron line. This value is listed in brackets in Table 1. It was calculated from the equation

$$h\,\nu_0(\mathrm{Mev}) = \frac{-.51\ T\ (\mathrm{Mev})}{T - \sqrt{T(T+1.02)}\ \cos\phi}$$

which is developed from the Compton Scattering Formula. $h\,\nu_0$ represents the energy of the incident gamma-ray, $\phi$ the angle between the direction of the incident gamma-ray and that of the recoil electron and T the maximum recoil electron energy, in this case 2.14 Mev.

In the experimental arrangement, because of the relatively large size of the source as compared to that of the radiator, $\phi$ may have values from 0° to about 60° depending upon which portion of the source is considered. For $\phi = 0°$ we get $h\nu_0$ = 2.4 Mev (approx.). A different value of $\phi$, say 15°, leads to a higher gamma energy which in turn would give rise to a maximum recoil electron energy greater than 2.14 Mev. Since the maximum recoil electron energy detected was 2.14 Mev, it was concluded that the gamma-ray responsible for it was that at 2.4 Mev.

As noted previously, cut-off at the lower end of the spectrum occurs at 50 Kev, because of window thickness. Therefore the spectrometer is not efficient in the detection of gamma-rays whose energies are below about 138 Kev (50 Kev plus the lead K-shell binding energy of 88 Kev). L-shell photoelectrons might still be ejected but the fact that the probability of their ejection is far less than that for the K-shell effectively rules out the possibility of detecting them.

The comparative chart in Table 1 shows fourteen gamma-ray energies found in this study. One of these, that at 2.4 Mev is quoted only approximately since it is calculated from the Compton end-point. Of the fourteen, all but one correspond reasonably well to values found by earlier investigators. The remaining one, at 0.45 Mev is a very weak line, as may be seen from Figure 12, and occurs between two relatively strong lines. Because of its low intensity, much time was spent in making observations on it and raising its statistical accuracy to a figure comparable to that of the more intense lines. Should such a line actually exist, it is certain that its intensity is near the limit of detection of the spectrometer used.

Many gamma-ray energies, reported by other workers were not observed here. This might be due to their low intensity or perhaps to the fact that they are highly converted and hence have little intensity left for photoelectron emission. It may be noted that in the region of the spectrum above 1.1 Mev, according to the present study the picture is similar to that given by Ellis and Skinner. Of the several other energies given by Alichanov and Latyshev in this region no trace could be found, in spite of the fact that they are quoted as being of relatively high intensities.

## V. BIBLIOGRAPHY


A. Alichanov and G. Latyshev — C.R.Acad.Sci. (U.R.S.S.), 20, 429 (1938).

J. Backus — Phys.Rev., 68, 59 (1945).

J. M. Cork — "Radioactivity and Nuclear Physics", (Van Nostrand).

C. D. Coryell, M. Deutsch, R. D. Evans, W. J. Ozeroff et al — "The Science and Engineering of Nuclear Power", (Addison-Wesley).

J. Danysz — Le Radium, 9, 1 (1912); 10, 4 (1913).

M. Deutsch, L. Elliott and R. D. Evans — Rev.Sci.Instr., 15, 7 (1944).

C. D. Ellis — Proc.Roy.Soc., 138, 318 (1932).

C. D. Ellis and H. W. B. Skinner — Proc.Roy.Soc., 105A, 165 (1924).

A. L. Hughes and V. Rojansky — Phys.Rev., 34, 284 (1925).

H. Robinson and E. Rutherford — Phil.Mag., 26, 717 (1913).

R. A. Tricker — Proc.Camb.Phil.Soc., 22, 454 (1924).

S. T. Tsien — Phys.Rev., 69, 38 (1946).

K. C. Wang — Zeits.fur Phys., 87, 633 (1934).