The Radiations Emitted from Artificially Produced Radioactive Substances

II. The Gamma-Rays from Several Elements

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A method for measuring the energy and relative intensity of the gamma-rays emitted by light radioactive elements is discussed. It depends upon the measurement of the momentum distribution of the Compton recoil electrons projected from a thin mica radiator situated in a cloud chamber traversed by a magnetic field. In the energy range from 0.5 to 5 Mev the distribution includes only those electrons whose initial velocity makes an angle of less than 10° with the path of the incident gamma-ray. The theoretical distribution curves indicate an average expected half-width of about 250 kv. Experimental data have been obtained which completely validate the theory. The gamma-radiations from A^{41}, Na^{24} and N^{13} have been investigated by this method. The argon radiation appears to be monochromatic with an energy of 1.37 Mev. Sodium emits three lines at 0.95, 1.93 and 3.08 Mev which are possibly interrelated. Also the two quanta annihilation radiation from the positrons of radio nitrogen was checked at 0.51 Mev. The results indicate that the method is quite satisfactory in the energy range from 0.5 to 3 Mev.

1. INTRODUCTION

UNDOUBTEDLY the best method of investigating the gamma-radiation emitted by the natural radioactive bodies consists of an examination of the momentum distribution of the electrons emitted by these substances. Superimposed on the β distribution (if present) are the groups of electrons originating from the internally converted gamma-rays. The investigation is usually carried out with the magnetic spectrograph. Unfortunately this method is not applicable to the radiation from nuclear disintegration processes nor to the gamma-rays from the lighter artificially produced radioactive bodies, since the probability of internal conversion is very small here.

The method of measuring the direct absorption of the gamma-rays has been most frequently used in the past in nuclear physics for determining their energy. It is becoming apparent, however, that this method is extremely untrustworthy, even when applied by careful investigators. Furthermore it will not resolve a complex spectrum.

It is possible to estimate gamma-ray energies if one has a knowledge of the energy distribution of the secondary Compton electrons knocked forward by it. A rough indication can be obtained by measuring the absorption of the Compton recoil electrons in matter. This has been done by the use of coincidence counters. A superior method, however, is to measure their momentum (and therefore their energy) as they traverse a cloud chamber situated in a magnetic field.[1]

Crane, Delsasso, Fowler and Lauritsen have pointed out that it is preferable to use a light element as a "radiator" of Compton electrons because of the masking effect of large radiative energy losses and pair production, both of which are much more prevalent for substances of high atomic number. The number of photoelectrons is also greatly decreased by using a radiator of aluminum, say, rather than lead. With the former, from a gamma-ray of energy 0.5 Mev less than one track in four hundred is due to a photoelectron. On the other hand, for 5 Mev radiation one electron in twenty should belong to a pair.

With these considerations in mind, then, it was thought desirable to make a calculation of the momentum distribution of the Compton recoil electrons ejected from varying thicknesses of radiator by a gamma-ray of energy in the range 0.5–5 Mev.

2. CALCULATIONS

One can determine the distribution in energy of the Compton recoil electrons ejected from an infinitely thin radiator by applying the theory of Klein and Nishina,[2] who show that the prob-

[1] Skobeltzyn, Zeits. f. Physik **43**, 354 (1927); **58**, 595 (1929); Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **48**, 125 (1935).
[2] Klein and Nishina, Zeits. f. Physik **52**, 853 (1928).

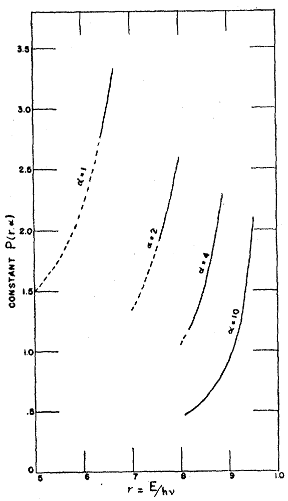

FIG. 1. Relative probability (on the theory of Klein and Nishina) that a gamma-ray of energy α will project an electron of energy r. The solid part of the curve concerns those electrons whose initial velocity makes an angle of less than 10° with the path of the incident gamma-ray.

ability that a gamma-ray will project an electron with an energy between E and $E+dE$ is

$$P_E dE = \frac{\pi e^4}{m^2c^4}\cdot\frac{1+(1-b)^2}{\alpha}\times\left[1+\frac{\alpha^2 b^2}{\{1+(1-b)^2\}(1+\alpha b)}\right]dE,$$

where m and e are the rest mass and charge of the electron, $\alpha = h\nu/mc^2$ is the energy of the incident gamma-ray in terms of the rest energy of the electron, and $b = E/(\alpha(h\nu - E)) = r/(\alpha(1-r))$ where $r = E/h\nu$. Thus it appears that the energy distribution of the recoil electrons projected from an infinitely thin radiator is proportional to $P_E = P(r, \alpha)$ given by the above expression.

As a result of applying the conservation laws to the process, the equation

$$r = 2\alpha/(1+2\alpha+(1+\alpha)^2 \tan\phi)$$

is obtained, where ϕ is the angle between the path of the incident gamma-ray (hereafter to be called the "forward direction") and the initial velocity of the electron. From this equation we see that a determination of r and ϕ would yield a knowledge of the gamma-ray energy α. Unfortunately, a measurement of the angle ϕ is rather uncertain due to the scattering of the recoil electrons in the radiator. An accurate measurement of ϕ and a reasonable number of recoils are incompatible.

It is possible to obtain a useful statistical treatment, however, by determining the energy of all electrons whose initial velocity makes an angle less than ϕ^*, say, with the forward direction. In order to obtain a sufficient number of tracks from gamma-radiation of 3 Mev, or less, it is necessary to take ϕ^* as large as 10°. Thus the form of the function $P(r, \alpha)$ is of importance only for $r_{10} < r < r_0$. Fig. 1 shows this function for several different values of α.

In practice, of course, a radiator of finite thickness is used. In order to extend the treatment to this case we can proceed in the following manner. We concern ourselves with the recoil electrons projected from a plane situated at a distance Δx, say, below the surface of the radiator, and parallel to it. If the electrons arising in this plane all had the same energy, their momentum distribution as they emerged from the surface after traversing the distance Δx in the radiator would correspond to the well-known straggling curves for homogeneous β-particles. The form of the straggling curve as obtained by White and Millington[3] is applicable here provided that Δx be small in comparison with the total range of the electrons.

The fact that the energy of the electrons is not homogeneous but has a distribution proportional to $P(r, \alpha)$ will have an effect on the shape

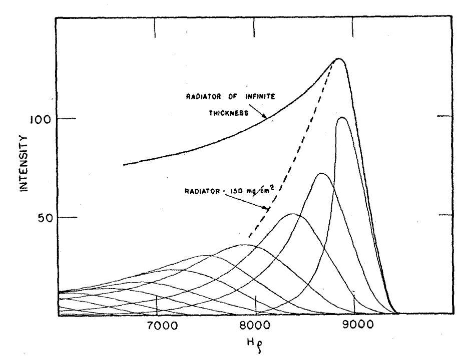

FIG. 2. Integration of component curves to obtain the total momentum distribution of the recoil electrons projected within 10° of the forward direction. The broken curve indicates the distribution to be expected from a radiator of 150 mg/cm². The full curve applies to a radiator of effectively infinite thickness.

[3] White and Millington, Proc. Roy. Soc. **A120**, 701 (1928).

of the straggling curves. This effect was investigated by graphical integration and was found to result principally in a further displacement of the peak and a corresponding broadening of the curve as a whole, but the shape remained much the same.

These resulting curves, then, some of which are shown in Fig. 2, will give the actual distribution in momentum as they emerge from the surface, of those recoil electrons which are ejected by a gamma-ray in the plane considered within 10° of the forward direction. If one neglects those electrons (about 10 percent in number) whose velocity originally makes an angle greater than 10° with the forward direction but which are scattered into the 10° zone, these curves will give the momentum distribution of the electrons which leave the surface within 10°.

In order to obtain the total momentum distribution of the electrons which are projected from all parts of the radiator, one must effectively integrate the above curves throughout its thickness. This has been done by graphical means, and the process is illustrated by Fig. 2 for a gamma-ray of energy 2.6 Mev.

Expressing a thickness of radiator by means of its surface density, we have allowed Δx to take on the values 25, 75, 125, . . . mg/cm^2 in this case. The size of each component is adjusted so that the area under the curve is proportional to the fraction of electrons transmitted by the thickness of radiator Δx corresponding to that particular curve. But this fraction, if there were no angular restriction imposed, would be merely the ordinate in the familiar range determination curves for homogeneous electrons.[4]

The effect of an angular restriction upon the range determination curves has been examined to a certain extent by Eddy who finds that it

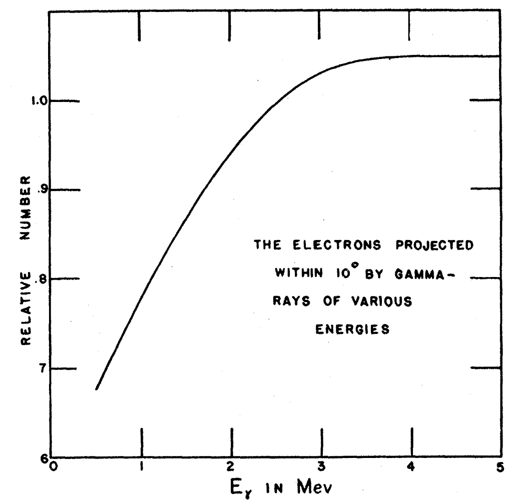

FIG. 3. The relative number of electrons projected within 10° of the forward direction, as a function of the energy of the gamma-ray. This applies to a radiator of infinitesimal thickness.

results, naturally, in a reduction of the "apparent range." This effect, however, is largely counterbalanced by the fact that a number of the Compton electrons which are given a recoil at an angle greater than 10° (and a correspondingly small energy) are scattered into the favored angle.

In Fig. 2, then, the sum of the three tallest curves should give approximately the momentum distribution to be expected from a radiator of surface density 150 mg/cm^2 under the angular restriction imposed. Similarly an estimate is shown of the asymptotic distribution to be expected from a radiator of infinite thickness.

This procedure has been carried through for several gamma-ray energies ranging from 0.5 Mev to 5 Mev, and the results are summarized in Table I which gives the total width in $H\rho$ of the momentum distribution curve at half-maximum value, to be ejected from radiators of varying thickness and at divers energies. (In the region considered the corresponding widths in kv may be obtained quite closely by multiplying the $H\rho$ by 0.3.)

From a table such as this one can obtain a fair idea of the most suitable radiator to employ in a given problem. It is obvious that for low energies one should use a radiator of thickness 50 mg/cm^2 or less if one is to obtain a sharp line corresponding to a monochromatic radiation.

TABLE I. *Total width in $H\rho$ of the momentum distribution of Compton electrons from γ-rays of energies ranging from 0.5 to 5 Mev.*

E in Mev	0.5	1.0	2.0	3.0	5.1
150 mg/cm^2	800	900	1000	1200	2000
100 mg/cm^2	800	700	800	1000	1700
50 mg/cm^2	400	400	600	700	1600

[4] Varder, Phil. Mag. **29**, 726 (1915); Madgwick, Proc. Camb. Phil. Soc. **23**, 970 (1927); Eddy, Proc. Camb. Phil. Soc. **25**, 50 (1929).

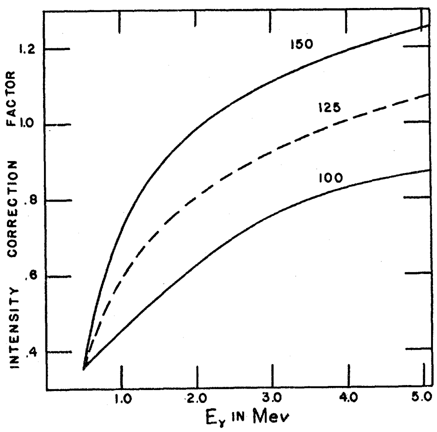

FIG. 4. The relative number of electrons projected from radiators of thickness 100, 125, 150 mg/cm² within 10° of the forward direction, as a function of the gamma-ray energy. Division of the experimental data by the ordinate of the proper curve will give the relative intensity of different lines.

However, at higher energies a somewhat thicker radiator would be preferable, since an increase in surface density from 50 mg/cm² to 100 mg/cm² will double the number of tracks obtained without appreciably broadening the momentum distribution curve of the recoil electrons.

3. Intensity Relations

From 3 Mev to 5 Mev, it would seem that the increase in half-width is due primarily to the Compton energy spread corresponding to a ϕ^* of 10° (Fig. 1). Thus a smaller ϕ^* is desirable for higher energies. Unfortunately, however, as ϕ^* becomes smaller, the scattering of the recoil electrons in the radiator becomes more important. This factor, combined with the prevalence at high energies of large radiative losses and pair production, will all tend greatly to broaden the momentum distribution curves in the region above 5 Mev.

Skobeltzyn pointed out that the number of electrons projected by a gamma-ray within twenty degrees of the forward direction is approximately independent of its energy, at least in the region of the gamma-rays emitted by the natural radioactive bodies. We have investigated this point by integrating $P(r, \alpha)$ with respect to dr from r_{10} to r_0. The results are plotted in Fig. 3.

This curve is valid for an infinitely thin lamina, but experimentally one is concerned with radiators of finite thickness. Thus the effect of straggling, etc., on the intensity function must be investigated. Accordingly we take a family of curves corresponding to a certain energy as illustrated by Fig. 2 and normalize the tallest according to Fig. 3. Then the area under the various summation curves should give the relative number of electrons projected within the 10° angle for that gamma-ray energy and for the various thicknesses of radiator. As a convenient experimental measure of the intensity we shall take the area included under the distribution curve between the abscissae corresponding to half the maximum value of the ordinate. The results are plotted in Fig. 4.

The final intensity factor should embody a correction involving the different solid angle subtended by the chamber for tracks of varying radius of curvature. This correction, however, will depend upon the experimental criterion for the selection of tracks and can be made quite small.

4. Energy Determination

In order to obtain the energy of the gamma-ray from the momentum distribution of the Compton recoils, it is necessary that some quantitative method of accomplishing this be decided upon. It would seem that the shape of that part of the curve from the peak to the high energy tail would be the part most likely to be independent of chamber conditions. It is reasonable, then, to relate the energy of the gamma-radiation to the intersection with the momentum axis of the best straight line which one could pass through this part of the curve.

Before this can be done it is necessary to investigate the change produced in the shape of the distribution curve by assigning an uncertainty to the individual momentum measurements. This has been done, using familiar analytical methods based on the Gaussian law of errors. Naturally, if an uncertainty in the individual momentum measurements is allowed, we must expect a broadening of the distribution curve as a whole, and a flattening of the high energy tail.

Quantitatively it is found that the intersection of the "best straight line" with the momentum axis is advanced approximately 0.9δ towards higher energies, if δ is the individual probable error assigned. Such a probable error will cover the uncertainty due to small angle scattering of tracks in the chamber, actual uncertainty in measurement of the tracks, etc.

In constructing the distribution curves it has been found that the above intersection point is about 3 percent lower than the momentum corresponding to the maximum recoil energy available to the electrons from a given gamma-ray. Actually a reasonable value of δ is about 3 percent. Therefore, no great error will be made if we take the intersection of the extrapolated linear portion of the curve as being the maximum momentum available to the electrons.

Test of this procedure on a few tracks (70) of electrons projected by the gamma-radiation of Th C″ showed that an error of less than 2 percent was made in the energy determination of the line at 2.62 Mev. The shape of the distribution curve also corresponded closely to the theoretical expectations.

5. Experimental Results

In order to indicate the validity of the above reasoning, some experimental results obtained by one of us (JRR) are included. The data given here supersedes that given previously.[5, 6]

The experimental details of the cloud chamber and magnetic field have been described by Kurie, Richardson and Paxton in the first paper of this series.[6] For these investigations, however, a thin lamina of mica or glass was mounted near the center of the cloud chamber perpendicular to its plane. The upper edge of the lamina was attached by means of water glass to the glass roof of the chamber. This was designed to act as the radiator of Compton electrons. As in the previous work, the cloud chamber was filled with hydrogen to reduce the scattering of the recoil electrons.

The gamma-ray source was placed on the perpendicular bisector of the radiator, in the plane of the cloud chamber, and about 30 cm outside the latter's side wall. The solid angle subtended by the source at this distance was sufficiently small so that the angular restriction could be imposed with confidence.

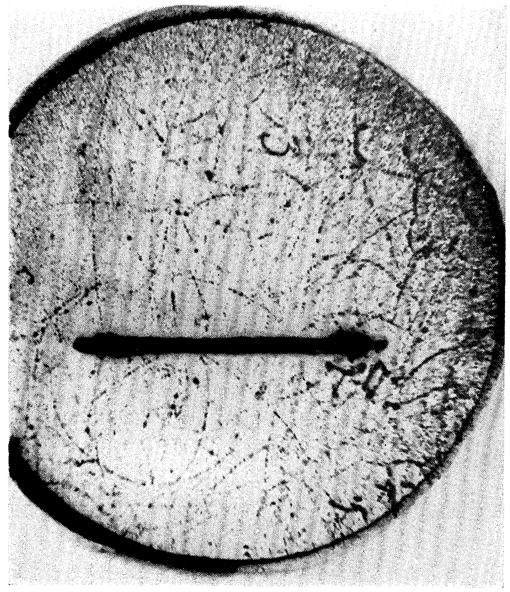

FIG. 5. Compton recoil electrons projected from a thin mica lamina (120 mg/cm²) by the gamma-rays of radio sodium. The track emerging from the radiator on the extreme left satisfies all the criteria. The next one to the right is just barely measurable from the point of view of clearness and angular deviation. None of the rest of the tracks are satisfactory.

For the selection of tracks the following criteria were formulated. An electron track must satisfy them in order to be included in the data. (1) The track must be clear and of uniform curvature. (2) It must appear to originate in the mica radiator. (3) It must emerge from the radiator within 10° of the forward direction. (4) It must be at least 10 cm in length. (5) It must not be visibly associated with a positron in the formation of a pair. To satisfy criterion 2, all tracks which became visible within 1 cm of the radiator were taken as originating in that body. Due to the geometry of the chamber a track 10 cm long would make an angle of less than 10° with the plane of the chamber. Fig. 5 indicates the geometry used.

In order to suppress statistical fluctuations to some extent, the experimental distributions have been smoothed slightly. The data as taken are grouped into half-centimeter intervals of radius of curvature. These are grouped in pairs to give one set of points on the distribution curve, and then regrouped to give another set. One set is denoted by circles, the other by points on the distribution curves.

[5] J. R. Richardson, Berkeley Meeting, Am. Phys. Soc., Phys. Rev. **49**, 203 (1936).

[6] Kurie, Richardson and Paxton, Phys. Rev. **49**, 368 (1936).

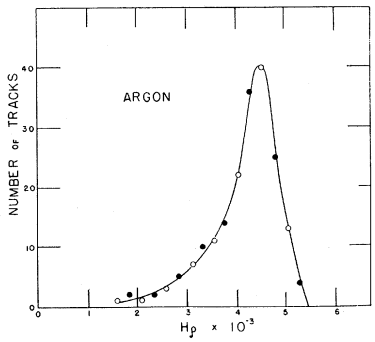

FIG. 6. The momentum distribution of the Compton electrons projected by the gamma-radiation from activated argon.

6. ARGON A^{41}

The radioactivity excited in argon by deuteron bombardment has been investigated by Dr. A. H. Snell.[7] He kindly prepared a sample of the radioactive gas which was compressed into a small thin-walled container and thus used as a gamma-ray source.

The radiator used was of glass and has a surface density of about 120 mg/cm². Approximately a hundred measurable tracks were obtained from a group of three hundred pictures, although altogether there was about ten electron tracks per picture, most of which originated in the glass sidewalls.

The momentum distribution curve of the recoil electrons is shown in Fig. 6. One sees that the curve corresponds closely to the theoretical distribution to be expected from a single gamma-ray line. Since the latter has been checked by measurements on the high energy line of Th C″, it seems reasonable to suppose that the gamma-radiation of argon consists of a monochromatic line. Using the procedure explained in Section 4, it was found that the maximum momentum available to the Compton electrons was an $H\rho$ of 5280 gauss-cm corresponding to an energy of 1.15 Mev. When an electron of this energy is projected in the forward direction, a gamma quantum of energy 0.22 Mev is scattered directly backwards. Thus the radiation emitted by radio-argon must have an energy of 1.37 Mev. An estimated probable error of ± 0.06 Mev is assigned.

The certainty with which it can be asserted that the line is monochromatic is, of course, limited by the resolving power of the method. It would seem from an inspection of the curves of Fig. 2 that two lines of about equal intensity, but differing in energy by 300 kv or more, would be rather clearly resolved using this radiator. Thus it is possible to say that the line here is monochromatic to less than 200 kv. A thinner radiator, of course, would greatly improve the resolving power but would prove much more laborious in the yield of tracks.

[7] A. H. Snell, Phys. Rev. **49**, 555 (1936).

7. SODIUM Na^{24}

Radio-sodium as produced from its stable isotope by deuteron bombardment has been studied in detail by E. O. Lawrence.[8]

In the investigation of the gamma-radiation emitted by this body, a target of sodium fluoride was exposed to the deuteron beam. Measurements were commenced four hours after activation, allowing time for the ten second fluorine activity to decay. The strength of the source was estimated to be about four millicuries.

A series of 1100 pictures with this source furnished a yield of about 900 tracks satisfying the criteria used. These tracks when grouped, yielded the distribution curve shown in Fig. 7.

It seems obvious that the radiation emitted is complex, and that it consists presumably of at least three lines. The question of the relative intensity of the lines is of interest, assuming there are three. We can examine this question in the light of the considerations discussed in Section 3.

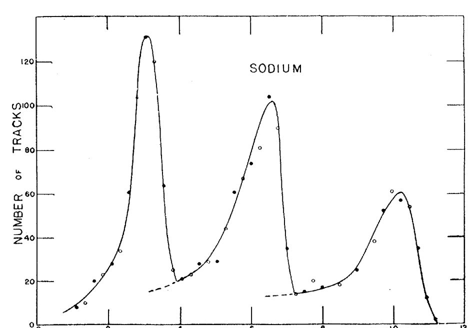

FIG. 7. Distribution curve of the electrons projected by the gamma-rays of radio-sodium. The maximum momentum available to the electrons from the assumed three lines is 3790 $H\rho$, 7150 $H\rho$, and 11,080 $H\rho$.

[8] E. O. Lawrence, Phys. Rev. **47**, 17 (1935).

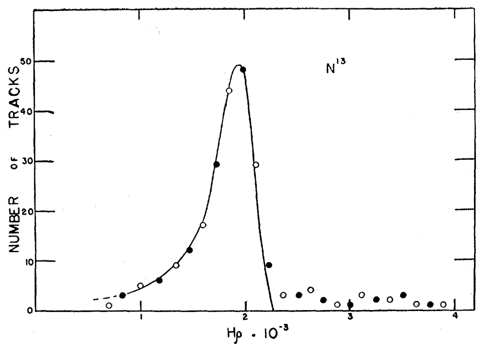

FIG. 8. Distribution curve of the recoil electrons produced by the radiation emitted when the positrons of radio-nitrogen are annihilated in lead. The maximum momentum available from the main line is 2280 $H\rho$.

From a knowledge of the radiator thickness (about 120 mg/cm^2 in this case) and the energy of the gamma-ray line, one can find the relative intensity correction factor from Fig. 4. Thus the relative intensity of the lines can be estimated from the momentum distribution of the recoil electrons. It is believed that the estimates can be made correct to within 20 percent.

The results of the measurements on Na^{24} are as follows:

Energy in Mev	0.95	1.93	3.08
Relative Intensity	1.05	0.95	0.65.

It is to be observed that the sum of the energies of the two lines of equal intensity is approximately equal to the energy of the third line.

Naturally, it is to be expected that the energy value assigned to the 3 Mev line is more precise than those given for the other two lines. Even for the lightest radiators practicable there will be a certain amount of "masking" of low energy lines due to the recoil electrons from a line of higher energy which suffer large energy losses in traversing the radiator. In many cases, however, this can be made negligible.

8. Radio-Nitrogen N^{13}

It was thought desirable to investigate the applicability of this method to the measurement of gamma-rays of a somewhat lower energy. An obvious monochromatic source of such a nature is the "two-quanta" radiation emitted when a positron at rest is annihilated. We may think of this process, of course, as the transition of an electron from a positive energy state $+mc^2$ to a negative energy state $-mc^2$. To satisfy the conservation laws of energy and momentum, two quanta of energy mc^2 each are radiated in opposite directions. Since this process of annihilation is by far the most probable,[9] we should expect a prominent monochromatic line at 0.51 Mev in the gamma-ray spectrum of a positron emitter.

Radio-nitrogen as formed from C^{12} by deuteron bombardment is a convenient positron emitter, so the radiations from it were investigated. McMillan[10] has examined the direct absorption in lead of the annihilation radiation from this source. He reports an accurately logarithmic absorption over a factor of 100 and a coefficient in good agreement with the theoretical one.

In this series of experiments a target of Acheson graphite was bombarded with 4 Mev deuterons. Because of the low energy of the expected radiation a mica radiator of only 40 mg/cm^2 was used. The magnetic field also was reduced to about 250 gauss. The target was placed with the bombarded surface towards the cloud chamber, and with a thin sheet of lead covering it, of sufficient thickness to stop all the positrons emitted by the radio-nitrogen.

The momentum distribution of the recoil electrons obtained in this way is shown in Fig. 8. It indicates the presence of a main gamma-ray line at 0.51 Mev, in excellent agreement with the value to be expected for the two-quanta radiation emitted when a positron is annihilated at rest. The occasional electron exhibiting a momentum greater than that to be ascribed to this main line may be due to contamination of the source. More probably, it may be due to the radiation emitted when a positron is annihilated while in motion. In this case, the quantum emitted in the forward direction will probably have an energy of mc^2 plus most of the kinetic energy of the positron.[9] It is also possible that the rare[11] one-quantum annihilation may be detected, in which the total rest energy of the pair is converted into a single quantum in the presence of

[9] H. A. Bethe, Proc. Roy. Soc. **A150**, 129 (1935).
[10] E. McMillan, Phys. Rev. **46**, 868 (1934).
[11] Jaeger and Hulme, Proc. Camb. Phil. Soc. **32**, 158 (1936).

a nucleus, the latter allowing the conservation laws to be satisfied. More work is being done to clear up this matter.

Upon consideration of these results, it seems to us that this method of measuring the energy and relative intensity of gamma-radiation is fairly satisfactory in the energy range from 0.5 to 3 Mev. As far as radiation emitted from the lighter elements is concerned, it appears to be the most reliable method so far used to obtain these quantities.

The authors are very grateful to Professor E. O. Lawrence and to Professor J. R. Oppenheimer for many discussions of this work. We are also indebted to the Chemical Foundation and the Research Corporation and the Josiah Macy, Jr., Foundation for grants making the experimental work possible.

DECEMBER 1, 1936 PHYSICAL REVIEW VOLUME 50

$K\alpha$ Satellite Lines for Elements Zn(30) to Pd(46)

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(Received September 21, 1936)

With a two-crystal spectrometer, ionization curves of the $K\alpha_{3,4}$ group of x-ray satellite lines have been recorded for elements Zn(30) to Pd(46). In this satellite group are found four component lines for elements $30 \leq Z \leq 33$, three components for $34 \leq Z \leq 40$ and two components, α_3' and α_4, for $41 \leq Z \leq 46$. The wave-length position, relative intensity, and line width at half-maximum intensity of each component has been measured. A sharp and anomalous decrease (with increasing Z) in the total satellite intensity relative to the α_1 intensity is found in the region of $Y(39)$. Curious and anomalous intensity relations are also found among the individual satellite components.

I. INTRODUCTION

EXPERIMENTAL knowledge of x-ray satellite lines has recently been advanced very considerably by the application of the two-crystal ionization spectrometer. Feeble ionization currents can now be measured with an accuracy which is limited chiefly by the statistical variation in the number of quanta entering the ion chamber,[1] and the ratio of two x-ray intensities differing by a factor of 10,000 can be measured with an uncertainty of but a few percent. Measurements with such precision combined with high resolving power are indispensable in obtaining quantitative information, especially of intensity relationships, about the extremely faint x-ray satellite lines accompanying the intense $K\alpha_1$ lines.

Wave-length positions, relative intensities and line widths are reported in the present paper for the component lines α_3, α_3' and α_4 for elements Zn(30) to Pd(46). This report extends a previous study[2] of the $K\alpha$ satellite lines and, with the previous study, provides systematic and relatively precise information about these lines for the wide atomic number range S(16) to Pd(46).

II. EXPERIMENTAL PART

The two-crystal spectrometer used in these measurements has been described elsewhere.[3]

Crystals

The calcite crystals were ground, polished and etched several times in an effort to make of them "perfect" crystals of Class I.[4] As these crystals were used, their degree of perfection was good though somewhat indefinite. No attempt was made in the present work to study *accurately* (i.e., to 1%) line widths and shapes, and our knowledge of the diffraction patterns of these crystals was considered adequate for the satellite study. As an index to the effective resolving power, the observed $K\alpha_1$ widths are given in a subsequent table of data.

* National Research Fellow.

† Indebted to the Carnegie Foundation for a grant-in-aid (made to Professor F. K. Richtmyer) of this research.

[1] L. G. Parratt, Phys. Rev. **49**, 132 (1936), and others.

[2] L. G. Parratt, Phys. Rev. **50**, 1 (1936).

[3] F. K. Richtmyer and S. W. Barnes, Rev. Sci. Inst. **5**, 351 (1934), and F. K. Richtmyer, S. W. Barnes and E. G. Ramberg, Phys. Rev. **46**, 843 (1934).

[4] L. G. Parratt, Rev. Sci. Inst. **6**, 387 (1935).

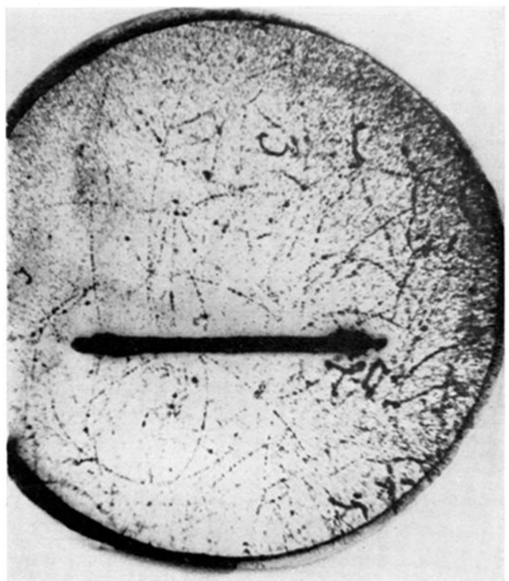

FIG. 5. Compton recoil electrons projected from a thin mica lamina (120 mg/cm^2) by the gamma-rays of radio sodium. The track emerging from the radiator on the extreme left satisfies all the criteria. The next one to the right is just barely measurable from the point of view of clearness and angular deviation. None of the rest of the tracks are satisfactory.