ber enhances the average magnitude. Thus the average burst size is increased nearly 50 percent by the presence of the 23 kg of lead, and while the paraffin had little effect on burst frequency in the lower ranges, it increased the average size by nearly 30 percent.

Analysis of these average values shows that in the "half-shield" condition less than 10 percent of the total ionization in large bursts is contributed by those greater than 90×10^6 ions, but when the paraffin is added these large bursts contribute more than 25 percent of the total, and with the lead the fraction goes up to nearly 40 percent. Thus it becomes evident that the material above the chamber increases by many fold the number of bursts in the very high ranges. If sufficient data were available to give significant rates in these regions, the slopes of our curves in Fig. 2 (c) might be considerably changed. There is also an indication that more than one exponential would be necessary to express the distribution, as was found in earlier work[2] with the meter fully shielded.

If bursts are conceived as consisting of many rays originating in and diverging from a small volume, then the size of the burst as recorded by an ionization chamber will depend on its proximity to the point of origin of the rays. The evidence to date indicates that material is necessary for the production of bursts. Therefore the placing of material directly on the ionization chamber is equivalent to bringing the chamber near to a source of bursts, with a resulting increase in average burst size. From this point of view our results may be interpreted as further evidence that bursts originate in material, and that they consist of many rays originating in and diverging from a small volume.

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Beta-Ray Spectra of Radioactive Manganese, Arsenic and Indium

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The beta-ray spectra of radioactive manganese, arsenic and indium was obtained by measuring tracks produced in a cloud chamber situated in a magnetic field. Manganese and arsenic give spectra which can be resolved into two components. The end points of the two components are: for Mn, 1.2 and 2.9 MEV; for As, 1.09 and 3.4 MEV. The endpoint for In is 1.45 MEV.

IN view of the importance of the study of the beta-ray spectra of natural and artificially radioactive substances we have investigated the energy distribution of the electrons emitted from radioactive manganese, arsenic and indium produced by the capture of slow neutrons. It is of interest to see whether the energy distribution of the disintegration electrons fits the theory of Konopinski and Uhlenbeck[1] and also to determine the endpoints of the spectra. While this work was in progress the results of a similar investigation were published by Gaerttner, Turin and Crane.[2] These investigators studied, among other elements, radio-indium and radio-manganese, and their results will be discussed in relation to those obtained by us.

APPARATUS

The beta-ray spectra of radio-manganese, arsenic and indium were studied by analyzing the tracks obtained in a Wilson cloud chamber situated in a magnetic field. The chamber, a modification of the magnetically operated one described by Dahl, Hafstad and Tuve,[3] was driven by two electromagnets, one of which compressed and the other expanded the chamber from its equilibrium position. This reduced the load on the magnets and increased the pressure range which could be used. The active part of the

[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. **48**, 7 (1935).

[2] E. R. Gaerttner, J. J. Turin and H. R. Crane, Phys. Rev. **49**, 793 (1936).

[3] O. Dahl, L. R. Hafstad and M. A. Tuve, Rev. Sci. Inst. **4**, 373 (1933).

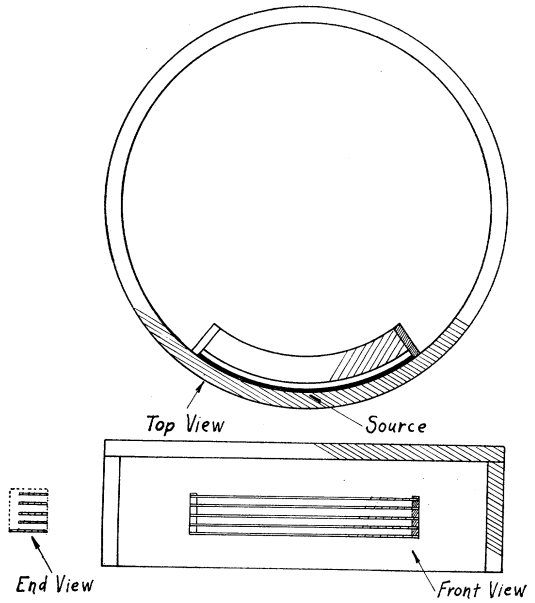

FIG. 1. Cloud chamber and slit system.

chamber, 13 cm in diameter and 4 cm deep, was separated from a secondary volume by a rubber diaphragm. When hydrogen was used in the chamber the secondary volume was also filled with hydrogen to cut down loss by diffusion.

The magnetic field was produced by a Helmholtz coil 15 cm in mean radius enclosed in a water-cooled brass case. The coil was capable of a maximum field of 800 gauss, constant to ± 1 percent throughout the volume of the chamber. The coil was calibrated by means of two different flip coils which agreed to two percent. The expansion and compression magnets produced a field of only one gauss in the chamber space and any inhomogeneity caused by them could be neglected. The electrostatic distortion of the tracks was minimized by grounding out the 90-volt sweeping potential at the instant of expansion.

A Sept camera with an f: 3.5 lens was mounted to photograph along the axis of the coil. Light was furnished by four mercury discharge tubes containing, in addition to the mercury vapor, about 7 cm of helium. Originally 10 mf at 4000 volts was discharged through each, but the tubes were found to burst quickly, sometimes at the first discharge. At present each is operated on 3.5 mf at 7000 volts. This represents nearly as large an energy as before, yet the present tubes have already withstood several thousand discharges without breaking. Sometimes a fresh tube would not fire at 7000 volts, in which case the tube was activated by an ignition coil. The ignition coils were excited by the discharge of 28 mf at 350 volts. Contactors for both the 7000 and 350-volt condenser banks were carried by the same relay. Aluminum mirrors were fixed to the backs of the discharge tubes and short focus cylindrical lenses were mounted on the tube holders to concentrate the light into a nearly parallel beam which illuminated only a narrow region in the chamber.

The radioactive samples were placed in the chamber behind a system of Soller slits, made of aluminum, and fastened to the periphery of the chamber (see Fig. 1). About one-half of the data on indium and manganese were obtained using slits which limited the electron beams to $\pm 5°$. The remaining half of the manganese data and all of that on arsenic were obtained from beams limited to $\pm 10°$. Only such tracks were recorded which were long enough to allow one to measure their curvature to ± 0.5 cm and which showed no deflection preceding the measurable portion of the track. Measurements were made by projecting the photographs on a card bearing a series of concentric circles spaced at 0.5 cm intervals.

In order to reduce the number of crooked tracks, the chamber was flushed with hydrogen which had been bubbled through isopropyl alcohol. This also aided in clearing the chamber after inserting a new sample. Tracks could be obtained after as few as ten expansions.

TREATMENT OF THE DATA

From the measured values of the radii of curvature of the tracks and the value of the magnetic field, a histogram was drawn showing the number of tracks in a given $H\rho$ interval as a function of $H\rho$. Care was taken, of course, to choose such a value of the field that there was no overlapping of intervals in the histogram. A Konopinski-Uhlenbeck plot, as suggested by Kurie, Richardson and Paxton[4] was then made from the data of the histogram. This was accomplished by plotting $(N/f)^{\frac{1}{4}}$ against $(1+\eta^2)^{\frac{1}{2}}$,

[4] F. N. D. Kurie, J. R. Richardson and H. C. Paxton, Phys. Rev. **48**, 167 (1935).

where N is the number of tracks in an interval, $(1+\eta^2)^{\frac{1}{2}}$ the total energy expressed in terms of m_0c^2, and $\eta=H\rho/1700$. It can be shown that[5]

$$f(Z,\eta)=\eta^2(2\pi y/(1-e^{-2\pi y})), \quad (1)$$

where

$$y=Z[(1+\eta^2)^{\frac{1}{2}}/137\eta]. \quad (2)$$

If one plots $(N/f)^{\frac{1}{4}}$ against the total energy one should obtain a straight line, provided that the theory is correct. In certain cases we have found that a straight line could not be fitted to the data. In this case we have been able, by trial, to fit two straight lines to the data, which results in a beta-ray spectrum of two components, the sum of which gives the original histogram.

Manganese

Radio-manganese was prepared by irradiating solutions of $KMnO_4$ or $NaMnO_4$ with neutrons and filtering off the MnO_2 which contained practically all of the activity. The filter paper was washed with distilled water until the wash water showed no purple color, indicating the absence of MnO_4 ion, and hence the absence of occluded Na and K ions. The data taken using $KMnO_4$ agreed to within the experimental error of about ten percent with that obtained using $NaMnO_4$, showing that there were no complications arising from K or Na. From one to two hours was required for filtering, drying and getting the chamber into sensitive operation so that the 3.75 minute period due to vanadium should have practically disappeared.

In order to minimize possible systematic errors, particularly those due to warping of the film on reprojection, half of the data were taken with a magnetic field of 378 gauss and the rest with a field of 490 gauss. The two sets of data agreed to within the experimental error.

The results of the experiments are shown as a histogram and K. U. plot in Fig. 2. The crosses of the K. U. plot correspond to the best curve which can be put through the histogram, and it will be seen that they deviate considerably from a straight line. On the other hand, one can try to resolve the data into two components by passing a straight line through the points of the K. U. diagram for values of $(1+\eta^2)^{\frac{1}{2}}$ greater than 3.0. The difference curve (lower energy component) then gives the straight line passing through the circles. Curve B, on the histogram, corresponds to the circles of the K. U. plot, while curve A corresponds to the straight line placed through the crosses for values of $(1+\eta^2)^{\frac{1}{2}}$ greater than 3.0. The sum of the two curves gives the original histogram, C. The two endpoints thus obtained are 2.9 MEV and 1.2 MEV.

The mean energy of the beta-ray spectrum is 0.56 MEV and one-half of the particles have energies less than 0.44 MEV. Amaldi, d'Agostino, Fermi, Pontecorvo, Rasetti, and Segrè[6] found, for the 2.5-hour period of manganese, a half-value thickness of 0.14 g/cm² of aluminum which corresponds to 0.45 MEV. Gaerttner, Turin and Crane reported a single group with a limit at

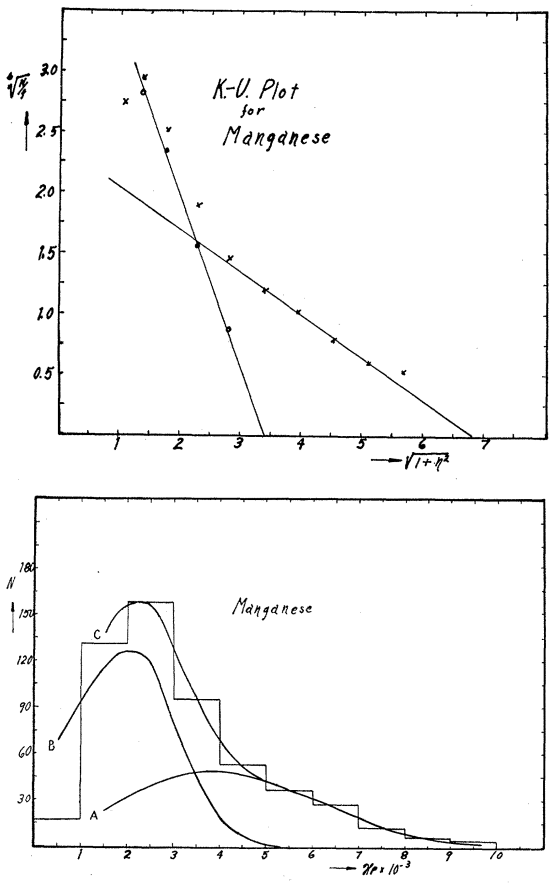

FIG. 2. Konopinski-Uhlenbeck plot and $H\rho$ histogram for the β-particles from radioactive manganese.

[5] The expression (1) for $f(Z,\eta)$ is true only for not too large values of Z. Dr. Harvey Hall has kindly worked out the exact expression for $f(Z,\eta)$ and we have found that for indium, $Z=49$, the correction to (1) is about 1 percent and can therefore be neglected in our calculations.

[6] E. Amaldi, O. d'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti and E. Segrè, Proc. Roy. Soc. **A149**, 522 (1935).

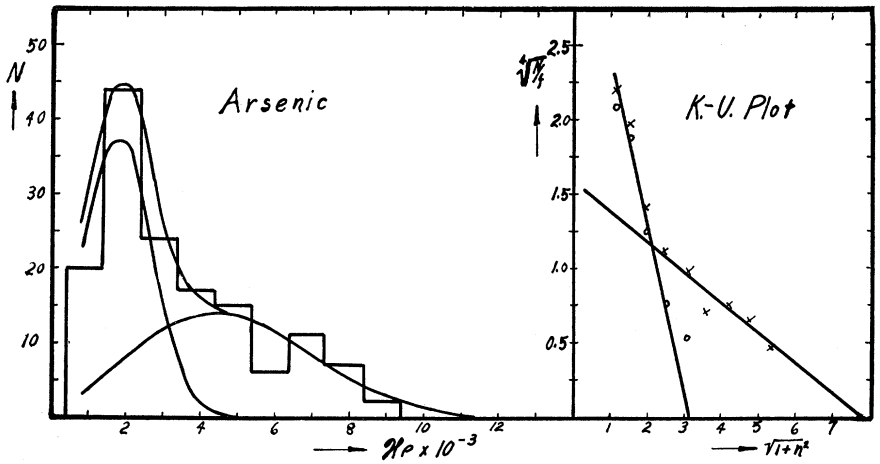

FIG. 3. $H\rho$ histogram and Konopinski-Uhlenbeck plot for the β-rays from radioactive arsenic.

2.8 MEV, while Alichanow, Alichanian and Dzelepow,[7] using a beta-ray spectrograph, reported an upper limit at 3.2 MEV.

The possibility that the high energy group might have a shorter period than the lower energy group was investigated by taking the ratio of the number of tracks having an $H\rho > 4900$ to those having an $H\rho < 4900$ as a function of the time after irradiation for any given sample. The results were erratic, due to statistical fluctuations, so that no exact conclusions could be drawn. The evidence, such as it is, is in favor of the two groups having the same period. It is known that radio-manganese emits gamma-rays but their energy has not been measured. It is possible that the difference in energy of the two beta-ray groups may be connected with the emission of the gamma-ray.

Arsenic

Radio-arsenic was formed by irradiating a solution of cacodylic acid with neutrons. After irradiation, a small amount of $AsCl_3$ was added, and the arsenic precipitated with H_2S. The results of the cloud chamber investigation are shown in the histogram and K. U. plot of Fig. 3. Following the procedure used in the case of manganese we denote by crosses on the K. U. plot the data taken directly from the histogram. As in the case of manganese the crosses do not fall on a single straight line. The K. U. plot can again be resolved into two straight lines, giving the two distribution curves which add together to reproduce the original histogram. The two groups show no difference in period.

The two endpoints obtained by this method are 3.4 MEV and 1.09 MEV, respectively. The mean energy is 0.62 MEV and one-half of the tracks have energies less than 0.45 MEV. For the 26-hour period of arsenic, Amaldi *et al.*[6] give a half-value thickness of 0.16 g/cm² of aluminum, which corresponds to 0.5 MEV.

Indium

Foils of indium, 0.1 g/cm² thickness, were irradiated by slow neutrons obtained by surrounding a 250-millicurie radon-beryllium source with 6 cm of paraffin. About half of the data were taken using the slit system and a vertical camera. The other half were taken without defining slits and with a pair of cameras inclined at 45° to the magnetic field. This arrangement yields much denser photographs, but seriously distorts tracks which are not in a horizontal plane, making them appear elliptical when projected. Relying on the collimation of the light beam to act as an effective slit and choosing only the longest tracks, it was found that the data obtained in this way were in agreement with those obtained using a slit system.

In view of the fact that a solid emitter was used whose stopping power varied from zero to 0.1 g/cm² it is clear that a K. U. plot of the uncorrected data can have no definite meaning. For example, a group of beta-rays, of approximately the same energy, coming from some

[7] A. I. Alichanow, A. I. Alichanian and B. S. Dzelepow, Nature **136**, 257 (1935).

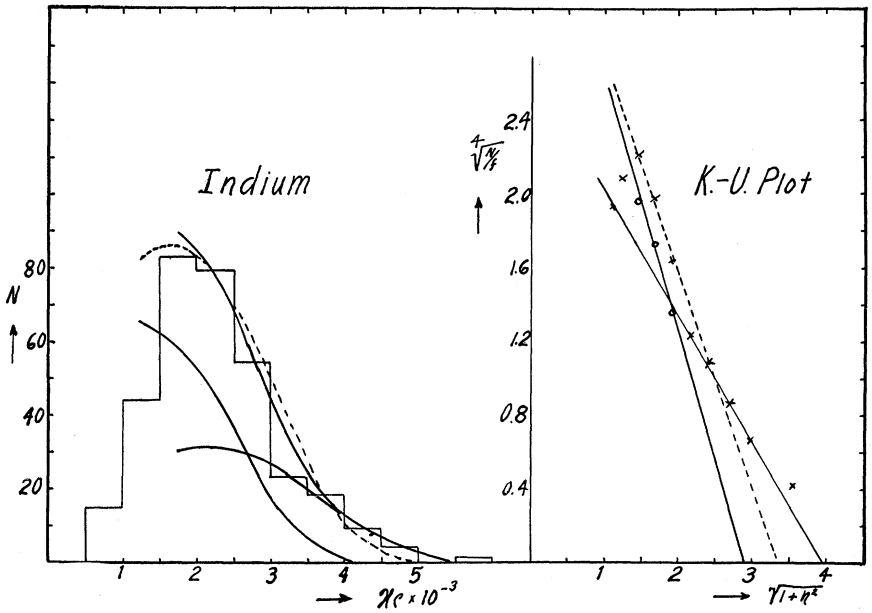

FIG. 4. $H\rho$ histogram and Konopinski-Uhlenbeck plot for the β-rays from radioactive indium.

place, a distance x from the surface of the emitter, would suffer a loss in energy in getting out of the emitter and there would also result a distribution in energy due to straggling.[8] The observed curve could then only be obtained by integrating the product of the true distribution function and the distribution function due to straggling. An overall correction, such as that applied by Gaerttner, Turin and Crane, will probably not give a very accurate reproduction of the true distribution curve from the observed one. On the other hand, it is reasonable to assume that the very fast particles near the end point come from the surface layers of the emitter. We have, therefore, tried to locate the endpoint of the beta-ray spectrum by passing a straight line through the high energy points of the K. U. plot given in Fig. 4. The endpoint thus obtained is 1.45 MEV, in reasonable agreement with that obtained by Gaerttner, Turin and Crane. It is clear from the diagram that no single straight line can be put through all the points of the K. U. curve. A resolution of the data, according to the method previously adopted, makes no improvement and is of no particular significance, since straggling is probably playing a large role at the lower energies.

[8] Rutherford, Chadwick and Ellis, *Radiation from Radioactive Substances* (Cambridge University Press, 1930), p. 424 *et seq.*

DISCUSSION

The use of hydrogen in the chamber reduced the number of crooked tracks to a small fraction of the total number. All tracks were recorded which presented an arc long enough to give an unambiguous measurement. The least definitive slit system used passed only particles lying within $\pm 10°$ to the horizontal. The horizontal component of such a path has more than 98.5 percent of the total energy. All tracks were assumed to lie in the same plane. The depth of the chamber illuminated was about 2 cm and the camera object distance was 40 cm, so that the maximum error from this source was about two percent, and the average error much less. The magnetic field was constant to one percent over the volume of the chamber and was known to one percent. The distortion due to turbulence was not determined, but it seemed to be small. The error in fitting a curve to any given track was less than 5 percent for $\rho = 5$ cm and should largely average out. The plausible spread within which the K. U. curves can be interpreted was not greater than ten percent. The effect produced by stray beta-particles caused by contamination, gamma-rays from the radon etc. which might be mistaken for disintegration electrons, was small. During the course of these

experiments a total of 180 have been measured. These showed a peak near $H\rho=1500$ and, by inspection, an upper limit at $H\rho=7500$ (1.8 MEV). Since the source holder covered only one-fourth of the circumference of the chamber wall, it does not seem likely that more than 45, or four percent of the "disintegration" tracks were spurious, and when the fourth root of the number of tracks is plotted, this would mean only a one percent change in a point on the K. U. plot.

In the case of manganese and arsenic the active sources were deposited chemically on filter paper. The amount of deposit was small so that the straggling of the beta-particles was presumably negligible. That this assumption was approximately correct is borne out by the fact that several sources, prepared from $KMnO_4$ and $NaMnO_4$, in which the amount of deposit varied, gave the same results to within ten percent. Furthermore, since the active sources were placed directly in the chamber, no corrections had to be made for the passage of the particles through metallic foils.

The two beta-ray components observed in manganese and arsenic may be connected with the emission of a gamma-ray. It is, of course, possible that the K. U. theory may not be correct and that a plot of $(N/f)^{\frac{1}{4}}$ against $(1+\eta^2)^{\frac{1}{2}}$ should not give a straight line. The theory, however, appears to fit existing data on other radioactive elements. The difference in results obtained in the present paper and those obtained by Gaerttner, Turin and Crane may be accounted for by the fact that they used thick emitters. This is somewhat borne out by the fact that the endpoint obtained by us for indium, using a thick emitter, is in substantial agreement with theirs. It should be pointed out that the procedure adopted by them, namely plotting $(N/f)^{\frac{1}{4}}$ for $Z=0$ is not correct for elements of atomic number as high as manganese (25) and may lead to erroneous results. We have replotted their results for indium and find that, while the shape of the curve is considerably changed when the correct value of Z is used, the extrapolated endpoint is not seriously effected.

The authors are indebted to Dr. D. P. Mitchell and Mr. G. A. Fink of Columbia University for preparing for us one of the sources of radio-manganese. We are indebted to Dr. C. B. Braestrup of the Department of Hospitals of the City of New York for many favors. and also to the American Association for the Advancement of Science for a grant to one of us (A. C. G. M.) with the help of which apparatus has been purchased.

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On X-Ray Satellites, Relative Intensities and Line Widths

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Preliminary data are reported on the $L\alpha_{1,2,3,4,5,6,7}$ lines for Ag(47) and on the $M\alpha, \beta$ lines for Au(79) recorded with a two-crystal spectrometer. But the primary purpose of this note is to indicate some of the difficulties in interpreting these and similar data. The disagreement between the present and earlier interpretations and results is large: a factor of about 2.5 in widths of M series lines, a factor or about 2 in α_2/α_1 relative intensities, and a factor of about 4 in the satellite relative intensities. These discrepancies are due to differences in (1) the effective resolving power of the instruments used and in (2) the assumed shapes of the component lines comprising an unresolved complex structure.

RADIATIONLESS transitions, or Auger effects, are assuming a major role in explaining and correlating several perplexing x-ray phenomena: the observed widths of x-ray emission lines and absorption limits,[1] and the relative

* The author is indebted to the Carnegie Foundation for a grant-in-aid (made to Professor F. K. Richtmyer) of this research.

[1] G. Wentzel, *Handbuch der Physik*, Vol. 24, Part 1 (1933), 768; F. K. Richtmyer, S. W. Barnes and E. G. Ramberg, Phys. Rev. **46**, 843 (1934); E. G. Ramberg and F. K. Richtmyer, Phys. Rev. **47**, 805A (1935); L. G. Parratt, Phys. Rev. **50**, 1 (1936); and others.