two elements did, but would lie on a line directly joining the points for the elements. The thermal conductivity of aluminum is definitely abnormal in its temperature variation, but the conductivities of all its usual alloys except those containing silicon are capable of close representation by a single curve at a given temperature.

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Statistical Fluctuations of Cosmic-Ray Ionization in New Recording Meter

The statistical fluctuations of the ionization due to cosmic rays inside a spherical chamber are related to the number of ionizing particles entering the chamber by the expression $\sigma = FI(N)^{-\frac{1}{2}}$, where σ is the standard deviation of a set of observations each extending over a time t, I is the total ionization and N the number of ionizing particles traversing the chamber during the time of one observation. The factor F is given by

$$F^2 = (9/8)\frac{\Sigma r_n \cdot \Sigma n^2 r_n}{(\Sigma n r_n)^2},$$

where r_n is the ratio of multiple to single rays and n is the number of associated shower particles.[1] If F were known accurately then it would be possible to determine N by measurements of σ. Actually F can only be approximated from drop track observations and the resulting value is certainly smaller than that which applies to shielded ionization chambers where the number of effective showers is undoubtedly larger than for the usual cloud chamber arrangement.

Recent analyses of records obtained from two precision recording cosmic-ray meters[2] running simultaneously side by side gave for the hourly statistical variation after elimination of bursts larger than 10^7 ions

$$\sigma_h = 33.4(10)^6 \text{ ions (meter No. 1)}$$
$$= 34.4(10)^6 \text{ `` (meter No. 2).}$$

Since the collecting systems were insulated for 57.5 minutes out of each hour, the standard deviation for one minute was $\sigma_m = 33.9(10)^6 \times (57.5)^{-\frac{1}{2}} = 4.41(10)^6$ ions.

The observed total ionization was $I = 94.8(10)^6$ ions/minute.

The value of F as estimated from Anderson's cloud chamber observations[3] is 1.32 but in our case where we have a 35.6 cm diameter ionization chamber surrounded by 12 cm of lead, this factor would be considerably larger. If we take $F = 1.5$ then the calculated value of N comes out to be 1035 particles per minute or 1.04 per cm^2 per minute.

The total ionization is

$$I = (4/3)RsfN\Sigma n r_n/\Sigma r_n,$$

where R is the radius of the ionization chamber, s the number of ions per particle per cm in air at one atmosphere and f is the factor of proportionality between the ionization in one atmosphere of air and 50 atmospheres of argon ($f = 67.0$). Taking $\Sigma n r_n/\Sigma r_n = 1.42$ which is again an estimate from cloud chamber observations, the calculated value of s is 47 ions/cm.

The smallest burst which can be detected with reasonable certainty with this apparatus is about 10^7 ions, which corresponds to 132 ionizing particles on the basis of the above value of specific ionization. Obviously there are smaller bursts which occur but are not detectable as such and presumably this still holds true for apparatus capable of detecting bursts involving considerably fewer particles. This suggests that some of the bursts at least are simply large scale showers.[4]

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June 29, 1935.

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On the Shape of the Distribution Curves of Electrons Emitted from Artificially Produced Radioactive Substances

No reliable method of finding the upper limit of the (momentum)-distribution curves of the electrons emitted from the nuclei of radioactive substances has as yet been devised. In the hope of finding a good statistical method of treating the histograms obtained from measurements of the curvatures of β-tracks in a cloud chamber we have been examining some experimental data in terms of the theory of Fermi[1] and also the modification of Fermi's theory introduced by Uhlenbeck and Konopinski.[2] We desire to give a brief account here of the ability of these theories to account for the shape of these distribution curves and to discuss their usefulness as methods of computation in getting the upper limits of such distributions without the arbitrariness usually involved in such work.

It appeared some time ago that the original Fermi theory gave a fairly good fit to our experimental curves and by using the theory in a form which will be indicated below we deduced the upper limits of several elements which were reported in April.[3] The tracks on which these results were based were photographed in a cloud chamber filled with oxygen. Feeling that our criterion of selection (that any track with a noticeable deflection was not measured) was discriminating against low energy tracks, we have repeated nearly all our previous work in a hydrogen-filled chamber which greatly reduces the scattering of the electrons. The new distribution curves have their peaks at a lower $H\rho$ and cannot be fitted by the old Fermi theory. At the suggestion of Dr. Arnold Nordsieck

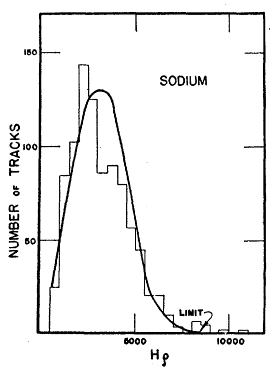

FIG. 1a.

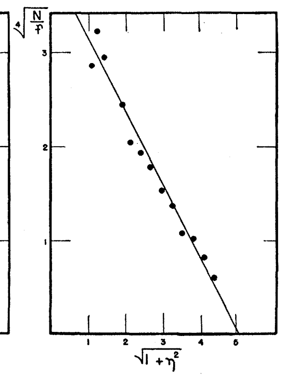

FIG. 1b.

FIG. 1 (a) The experimental histogram for the distribution in $H\rho$ of the electrons emitted from radio-sodium. The heavy smooth curve is a theoretical curve which has been fitted to the histogram by means of the plot in (b) where the same data are so plotted that a straight line is expected if the Uhlenbeck-Konopinski modification of the Fermi theory is valid. The few tracks beyond the upper limit are to be attributed to the strong γ-radiation emitted by radio-sodium.

we have tried fitting the Uhlenbeck-Konopinski formula to the data and found for the most part that the fits were gratifyingly good.

Fermi's formula for the probability that an electron of momentum $mc\eta$ be emitted may be written in the form

$$(1+\eta^2)^{\frac{1}{2}} = c - k[N/f(\eta, Z)]^{\frac{1}{2}}$$

where N is the number of tracks whose momenta lie within a certain class interval, $f(\eta, Z)$ is a function which may be computed from the Fermi theory, $c=(1+\eta_0^2)^{\frac{1}{2}}$ and k is a numerical constant. By plotting $(N/f)^{\frac{1}{2}}$ against $(1+\eta^2)^{\frac{1}{2}}$ one should get a straight line if the data conform to the theory. From the intercept c on the $(1+\eta^2)^{\frac{1}{2}}$ axis one may get the energy of the upper limit. The modification introduced by Uhlenbeck and Konopinski leads to a formula which differs essentially from this only in that the square root term of Fermi's formula becomes a fourth root. The immediate consequence of this is that the order of contact of the distribution curve with the $H\rho$ axis is raised to the fourth order and if this is true the difficulties of finding this upper limit directly—without having recourse to fitting a theoretical curve to the experimental data—become very great.

The elements on which we have fairly complete data are carbon, sodium, silicon, chlorine and potassium. The tracks of the electrons emitted from these elements after they have been activated by bombardment with deuterons have been photographed in hydrogen. The distribution curves for sodium and silicon are shown in Figs. 1a and 2a. Superimposed upon the experimental histograms are the theoretical (Uhlenbeck-Konopinski) curves which have been fitted by means of the straight line plots shown in Figs. 1b and 2b as explained above. In these straight line plots the excellence of the fit is perhaps more apparent

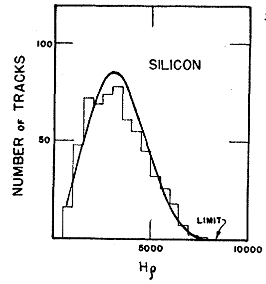

FIG. 2a.

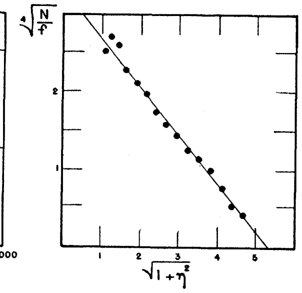

FIG. 2b.

FIG. 2 (a) The experimental histogram for the distribution in $H\rho$ of the electrons emitted from radio-silicon. Here again a theoretical curve has been fitted to the data by means of the plot in (b).

than real since the number of tracks in each column of the histogram enters the ordinate only as a fourth root. However the linearity of these plots is so much greater than a corresponding plot for the simple Fermi theory that one feels justified in attaching some value to the upper limits obtained in this way. We find in these two cases upper limits at $H\rho$ 8400 (2.1 mv) for sodium, and at $H\rho$ 8500 (2.1 mv) for silicon. In the case of sodium a few tracks from the hard γ-radiation emitted by this element make the determination of the upper limit from an inspection of the histogram very difficult, while for silicon no tracks have been found above $H\rho$ 8000.

For carbon an upper limit is indicated at $H\rho$ 7800 (1.9 mv) while no tracks have been found above $H\rho$ 7000.

Both chlorine and potassium are at present unsatisfactory in that they do not yield a single straight line but are readily decomposable into two straight lines and seem to indicate that the histograms are composed of two groups. A study of the γ-rays emitted from these substances is now being made in the hope of further unraveling these cases.

A more comprehensive and detailed account of the matters dealt with in this note will shortly be submitted to the *Physical Review.*

We are very grateful to Dr. Nordsieck for discussions and to Professor Uhlenbeck for private communications regarding his modifications to the Fermi theory.

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