The Energy Loss of Electrons in Carbon and the Decay of the Mesotron

In a recent issue of the *Physical Review* Fermi[1] suggested that the energy loss suffered by extremely fast particles in solid materials might be less than the loss in a corresponding amount of gas, because of the effect of the dielectric constant. This is of particular interest in regard to the mesotron, because direct measurements on its lifetime involve a comparison of its rate of absorption in solid and gaseous materials, especially graphite and air.[2] We have measured the energy loss in graphite for 10-Mev electrons, which are easily obtainable in the laboratory under controlled conditions. Since the magnitude of the effect of the dielectric constant depends essentially upon the ratio of the total energy of the particle to its rest energy, a 10-Mev electron should experience as great an effect as a mesotron of about 2000 Mev. Our results therefore apply to the case of the cosmic-ray measurements. Unfortunately there seems to be no feasible method of measuring energy loss in a gas, so we have simply compared our results with the values calculated by means of the Bloch formula.

A band of electrons of 8 to 12 Mev was selected out of the beta-ray spectrum of Li^8 by means of slits in a magnetic field. They then passed into a cloud chamber, across the center of which was placed a slab of graphite weighing 0.82 g/cm². A magnetic field of 3480 gauss was applied to the chamber. In this field a 10-Mev electron has a radius of curvature of only about 10 cm, and hence can be measured with great accuracy. Only those tracks making an angle of incidence less than 10 degrees with the normal to the absorber were used. The curvatures on the two sides of the absorber were measured and the changes in radius of curvature are plotted in Fig. 1. The average energy loss

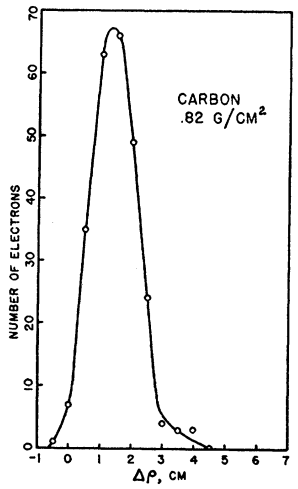

FIG. 1. Distribution of electrons with respect to change in radius of curvature.

for the 255 tracks observed is 1.86 Mev/g/cm². From the observed average angle of scattering (6 degrees in the projection) and the average angle of incidence the path length correction is estimated to be one percent. A correction of one percent should also be applied for the departure of the emergent tracks from the plane perpendicular to the magnetic field. Systematic errors (calibration of field etc.) amount to ±2 percent. If we assume that the breadth of the experimental curve is a fair indication of the magnitude of the *random* errors (such as changes in curvature due to scattering in the gas of the chamber), the probable error in the mean value from this cause is ±4 percent. Taking into account all these figures we get 1.82±0.08 Mev/g/cm² for the energy loss. From this we subtract the loss due to radiation, and have left 1.69±0.08 Mev/g/cm², which is the loss due to collisions alone. It may be mentioned here that the earlier measurements of Turin and Crane[3] give 1.8±0.2 Mev/g/cm² after corrections similar to the above are applied.

TABLE I. *Theoretical values for the collision loss for* 10-*Mev electrons.*

DIELECTRIC CONSTANT	EN. LOSS MEV/G/CM²	DIELECTRIC CONSTANT	EN. LOSS MEV/G/CM²
1.00	1.93*	1.5	1.60
1.01	1.90	2.	1.54
1.05	1.77	4.	1.46
1.1	1.71	10.	1.36
1.2	1.66		

* Bloch value.

Theoretical values for the collision loss for 10-Mev electrons, calculated by means of the Bloch formula and the Fermi formula for the dielectric constant effect are given in Table I. Our experimental value fits best with a dielectric constant of about 1.1, and, considering the probable error in our result, we may say that a dielectric constant of 1.05 to 1.5 is indicated. It may also be said, on the basis of this experiment, that the dielectric constant effect is by no means large enough to affect seriously the conclusions drawn from the experiment of Rossi, Hilberry and Hoag on the decay of the mesotron.

H. R. CRANE
N. L. OLESON
K. T. CHAO

University of Michigan,
Ann Arbor, Michigan,
March 6, 1940.

[1] E. Fermi, Phys. Rev. **56**, 1242 (1939).
[2] Bruno Rossi, H. Van Norman Hilberry and J. Barton Hoag, Phys. Rev. **56**, 837 (1939). Bruno Rossi, Cosmic-Ray Symposium, Chicago, June, 1939; Rev. Mod. Phys. **11**, 296 (1939).
[3] J. J. Turin and H. R. Crane, Phys. Rev. **52**, 63, 610 (1937).

Radioactive Zirconium and Columbium from Uranium Fission*

Radioactive zirconium and columbium have been obtained from a sample of uranium bombarded by slow neutrons from the Columbia cyclotron. In the zirconium separated from the uranium a strong 17.0-hour period was identified. From this a 75-minute period columbium has been observed to grow as a daughter product. Both of these have been shown[1] by Wilson-chamber observations to be negative electron emitters. This 75-minute columbium does not disintegrate into the 66-hour molybdenum reported by O. Hahn and F. Strassmann[2] from uranium, but our experiments do not as yet exclude a substantially longer or shorter period molybdenum daughter product from columbium.

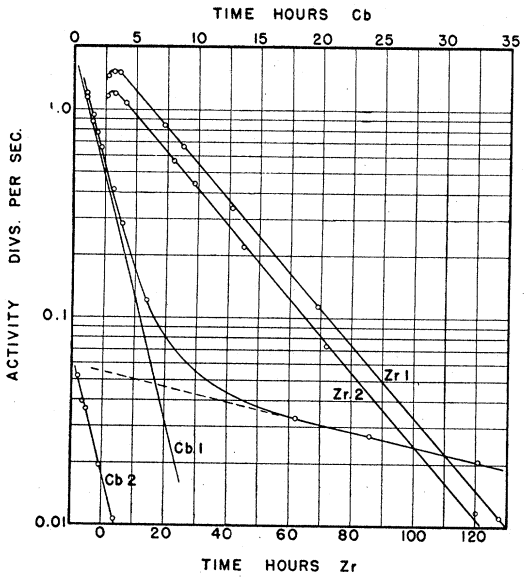

FIG. 1. Decay curves of zirconium and columbium from uranium.

An aqueous uranyl nitrate solution was irradiated for several days. The Zr was precipitated as a phosphate from a concentrated hydrochloric acid solution. To serve as carriers inactive isotopes of all previously reported fission products (i.e., Rb, Cs, Sr, Ba, Y, La, Mo, Sb, Te, Br, I) were added in quantities of a few milligrams each, previous to the precipitation. Simultaneously Th, Bi and Pb were added to carry down any natural radioactive bodies.

The zirconium phosphate precipitate was purified from traces of all other elements, except Hf and Pa, by means of the above precipitation; followed by a hydrogen fluoride and aqua regia treatment, coupled with a potassium sodium carbonate melt. (This chemical treatment will be described more fully in a chemical journal.) In order to prove that the observed activity was not associated with Pa or Hf, the Zr was fractionally crystallized as an oxychloride; it has been previously shown that by this treatment Pa[3] concentrates in the mother liquor, while Hf[4] accumulates in the front. The activities per milligram ZrO_2 after different chemical treatments were constant within experimental error. The decay curves of two typical Zr preparations are shown in Fig. 1. The average half-life was found to be 17.0 ± 0.2 hours.

A previously unknown radioactive columbium isotope was separated from the Zr. After addition of inactive Cb_2O_5, Cb was separated by (1) $KNaCO_3$-melt and precipitation from the filtrate with (*a*) HCl and (*b*) with NH_3 from an HCl solution, and (2) by a $NaHSO_4$-melt and precipitation from an acetic acid solution by hydrolysis. Two decay curves of this columbium are also shown in Fig. 1.[5] The period averaged from a number of such curves equals 75 ± 3 minutes.

The existence of mother-daughter relationship between the Zr and Cb was indicated by the build-up of the Zr activity after a Cb separation (see Fig. 1). Conclusive evidence was obtained by successive separations of Cb from the Zr. The data are given in Table I; while the Zr decayed by a factor of 7.7 the Cb yield decreased by a factor of 7.

TABLE I. *Evidence of mother-daughter relationship between* Zr *and* Cb.

SEPARATION	1	2
Age of Zr at moment of Cb separation (hr.)	23	74
Activity of Zr+Cb per 1 g ZrO_2 just before Cb separation (div./sec.)	68	8.8
Activity of Cb just after separation (div./sec.)	28	4.1

Absorption measurements indicate that the β-rays of both Zr and Cb have a maximum energy of about 1 Mev.

Evidence has also been obtained of a longer-life zirconium isotope, emitting electrons of low energy (about 0.25 Mev, with a period of more than 20 days.

The discovery of the above-mentioned products fills the gap in the light weight group of the previously known fission fragments. At least one radioactive isotope of every element between bromine (35) and ekamanganese (43) and antimony (51) and lanthanum (57) has now been reported. The large gap of seven elements between these two groups still remains unfilled.

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A. V. GROSSE
E. T. BOOTH

Department of Physics,
Columbia University,
New York, New York,
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[1] We are indebted to Mr. G. Weil for making the cloud-chamber experiments.

[2] O. Hahn and F. Strassmann, Naturwiss. **27**, 451, 544 (1939).

[3] A. v. Grosse, Berichte d. Deutsch. Chem. Ges. **61**, 238 (1928).

[4] G. v. Hevesy, *Das Element Hafnium* (1927), p. 6.

[5] The long period tail on Cb 1 is due to a trace (3 percent) of 17-hour zirconium as an impurity.

Compton Line Profiles Applied to Chemical Binding

The purpose of this letter is to describe a method which may be used in obtaining new information regarding the physical state of the electrons forming bonds in gaseous molecules and in solids. The method depends upon the experimental determination of the Compton line shape by the inelastic scattering of x-rays[1] or electrons[2] for the system whose electronic structure is being studied.

In order to apply such experimental information we shall make the fundamental assumption that all of the electrons in a molecule may, as far as their effect upon the line shape is concerned, be divided into classes each characterized by the rôle played in the molecule by the electrons of that class. In methane for example there are but two classes, the first consisting of the two equivalent K-shell electrons and the second of the eight equivalent electrons forming the four C—H electron-pair bonds. We shall then attribute to each class κ a line shape function, $y_\kappa(\beta)$, $(\beta=v/c)$, and the over-all line shape for the whole molecule will consist of the sum of the component line shapes, $y_\kappa(\beta)$, weighted