Electron Straggling in Thin Foils*

E. T. HUNGERFORD,† *Physics Department, University of Tennessee, Knoxville, Tennessee*

AND

R. D. BIRKHOFF, *Oak Ridge National Laboratory, Oak Ridge, Tennessee, and Physics Department, University of Tennessee, Knoxville, Tennessee*

(Received March 18, 1954)

A recent experimental investigation of electron straggling distributions reports disagreement with the distribution half-widths of the Landau-Blunck-Leisegang theory. Additional experimental work has been performed in which the angle of incidence of radiation on the foil has been more carefully controlled and a different method of comparison of theory and experiment has been employed. Discrepancies noted in the previous work with light elements are no longer found.

INTRODUCTION

THE theory of the processes by which electrons lose energy in penetrating matter has been reviewed recently.[1] In general, the energy distributions obtained by allowing a monoenergetic electron beam to impinge on a foil and then examining the resultant radiation with a beta spectrometer have agreed well with the theories of Landau[2] and Blunck-Leisegang[3] as regards the displacement of the peak of the distribution, i.e., the most probable energy loss. The shapes and, in particular, the widths of the distributions at half-maximum have also been measured and here the agreement has been less certain. Such measurements are critically dependent on at least three considerations: the energy spread of the initial radiation must be small compared to the spread obtained after passage of the beam through the foil; such initial variation in energy as does exist must be carefully taken into account before theory and experiment are compared; the geometry of the source-foil arrangement must be such as to insure that electrons which have suffered large-angle scatterings are not counted.

In the present work the above three factors have been carefully considered in the design of source-foil geometry and in the treatment of the data.

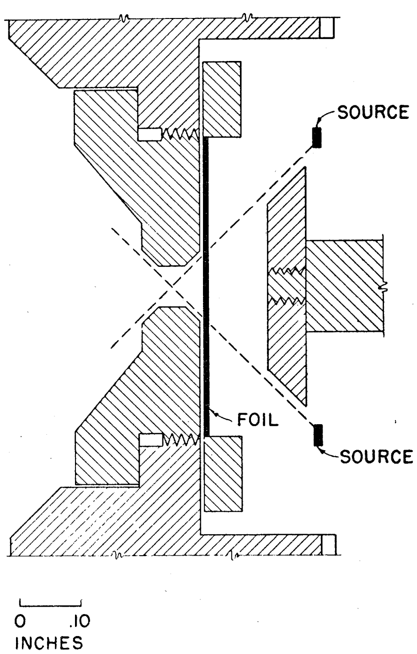

FIG. 1. Cross-sectional view of source and foil geometry.

APPARATUS

The spectrometer used has been described previously.[1] In the preceding experiment the approximately monoenergetic radiation from the K-conversion line of Cs^{137} was allowed to strike the foil through an angular range from 0 to 90°, whereas only the radiation leaving at $45° \pm 0.8°$ was accepted by the spectrometer. The source foil geometry in the present experiment is shown in cross section in Fig. 1. Calculations show that the angles of incidence with this arrangement lie between 45° and 55° with the exit angles defined as before. The new system possesses the additional advantage that the radiation must pass through a circular aperture of size calculated from the spectrometer theory[4] before entering the spectrometer, thus eliminating any ambiguity in the size of the source disk as seen by the spectrometer. That is, in the first experiment scattering of radiation in the foil could have been equivalent to a larger source due to the finite distance between source and foil. It will be noted from Fig. 1 that an annular ring source is required with the new arrangement. Source and backing thicknesses were such that the incident distribution had a momentum width of 0.98 percent, 0.98 percent, and 1.9 percent for the three sources used. These compare rather unfavorably with the theoretically obtainable resolution of 0.1 percent,

* Submitted by E. T. H. in partial fulfillment of the requirements for the degree, Doctor of Philosophy, at the University of Tennessee.
† Now with Shell Development Company, Houston, Texas.
[1] F. Kalil and R. D. Birkhoff, Phys. Rev. **91**, 505 (1953).
[2] L. Landau, J. Phys. (U.S.S.R.) **8**, 201 (1944).
[3] O. Blunck and S. Leisegang, Z. Physik **128**, 500 (1950).
[4] J. W. M. DuMond, Rev. Sci. Instr. **20**, 160, 616 (1949).

but the large source thicknesses were necessary to provide sufficient activity to permit reasonable counting rates on the energy loss distributions.

CALCULATIONS

The data as taken from the spectrometer consisted of a table of count rate minus background *versus* magnet current for the initial distribution, and for the energy loss distribution. Both curves were converted to energy distributions and plotted against energy.

Next the Blunck-Leisegang distribution was plotted against energy under the assumption of a monoenergetic incident beam. This distribution was then integrated numerically over the incident distribution and plotted, the integration being greatly simplified because the Blunck-Leisegang curve shape is essentially independent of a small variation in the incident beam energy. That is, the only effect of varying the incident energy was to shift the Blunck-Leisegang curve along the energy axis without altering its shape.

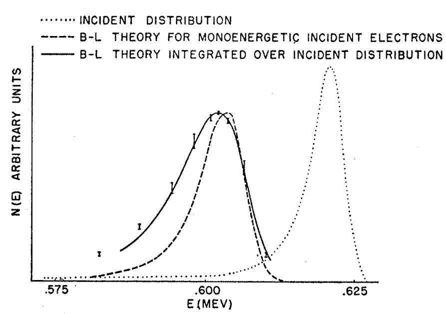

FIG. 2. Theoretical and experimental straggling distributions for 15.1 mg/cm² aluminum foil.

The experimental data were then compared with the integrated theoretical distribution. In the case of the very thick foils (−50 mg/cm²) the *L*-conversion line straggling distribution was calculated by reducing all ordinates in the experimental straggling curve by the *K*- to *L*-conversion ratio and shifting the curve upward in energy an amount equal to the difference in *K*- and *L*-binding energies. The resultant curve was added to the theoretical integrated distribution, whereupon comparison with experiment was made.

This method of treating the data differs considerably from that used previously, wherein the incident distribution was considered to be a Landau distribution and the foil thickness necessary to give this curve was added to the actual foil thickness. Unfortunately, the initial energy distribution could not be approximated very well by a Landau curve so this calculation method was abandoned in favor of the one above.

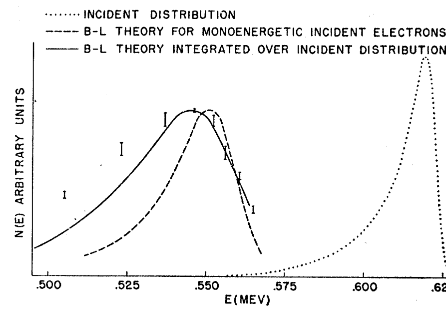

FIG. 3. Theoretical and experimental straggling distributions for 54.5 mg/cm² aluminum foil.

RESULTS

Principal disagreement with theory was found previously for the light elements. A typical straggling distribution for aluminum is shown in Fig. 2 as representative of the data taken with restricted angles of incidence and calculated as indicated. Given are the initial distribution, the theory assuming monoenergetic incident energy, this theory integrated over the initial distribution, and the experimental data. The foil thickness specified is the actual thickness multiplied by $\sqrt{2}$ to account for the oblique angles of incidence and of departure from the foil. Similar agreement between experiment and theory was found for the following foils: Al, 28.2 mg/cm²; Cu, 11.9, 28.0 mg/cm²; Ag, 14.8, 31.0 mg/cm²; Au, 29.0 mg/cm².

Figure 3 illustrates the departure from theory obtained when foil thickness is increased beyond the value permitted by the theory which neglects scattering and assumes that the cross section for a given energy loss in a single encounter is independent of the variation in energy of the electron as it passes through the foil. Agreement is still found for the high-energy side of the distribution, whereas there are many more low-energy electrons than predicted by the theory. Curves similar to this were found for Cu, 56.5 mg/cm²; and Au, 51.3 mg/cm². It is thought that the large increase in path length due to multiple scattering of the electrons in these thick foils is primarily responsible for the disagreement between theory and experiment in these cases.

CONCLUSIONS

Straggling distributions have been measured for a number of foils of various thicknesses and atomic numbers, and these distributions have been compared with the Landau-Blunck-Leisegang theory integrated over the initial energy distribution. Agreement within experimental error is found in all cases where foil thickness is kept within the limits set by the theory.