Lawrence Berkeley National Laboratory
Recent Work

Title
FLUCTUATIONS OP ENERGY LOSS IN SEMICONDUCTOR DETECTORS

Permalink
https://escholarship.org/uc/item/0fb517c4

Authors
Maccabee, Howard D.
Raju, Mudundi R.
Tobias, Cornelius A.

Publication Date
1966-02-17

eScholarship.org Powered by the California Digital Library
University of California

UCRL-16715

University of California

Ernest O. Lawrence Radiation Laboratory

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

FLUCTUATIONS OF ENERGY LOSS IN SEMICONDUCTOR DETECTORS

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

10th Scint. and Semi Cond. Counter
March 2-4, 1966

UCRL-16715

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

FLUCTUATIONS OF ENERGY LOSS IN SEMICONDUCTOR DETECTORS

Howard D. Maccabee, Mudundi R. Raju, and Cornelius A. Tobias

February 17, 1966

FLUCTUATIONS OF ENERGY LOSS IN SEMICONDUCTOR DETECTORS

Howard D. Maccabee, Mudundi R. Raju, and Cornelius A. Tobias

Lawrence Radiation Laboratory
University of California
Berkeley, California

February 17, 1966

Summary

Significant fluctuations and broadening of the energy-loss spectrum are expected in certain cases of passage of charged particles through "thin" detectors. Experimental measurements of this phenomenon (by use of lithium-drifted silicon detectors) are in good agreement with the rigorous theory of Vavilov, as tabulated by Seltzer and Berger.

Introduction

When an energetic charged particle passes through a detector, it loses energy by a series of collisions with the electrons of the detector material. In first approximation, the probability of an energy loss ϵ in a single electronic collision is proportional to ϵ^{-2}.[1] Thus collisions resulting in a large energy transfer to an electron are relatively infrequent compared with small-energy-loss collisions. Although they are relatively infrequent, the large-energy-loss collisions account for a significant proportion of the total energy transfer. In a "thin" detector (one in which the total energy lost is small compared with the kinetic energy of the particle), the probable number of large-energy-loss collisions may be so small that the random statistical fluctuations in this number result in significant fluctuations in the energy lost in this mode, and thus fluctuations in the total energy transfer occur. This phenomenon has been theoretically investigated by Landau,[1] Symon,[2] Vavilov,[3] and others, and is often called the Landau effect. Experimental investigations have been carried out by Gooding and Eisberg,[4] Rosenzweig and Rossi,[5] and Grew,[6] all of whom compared their data with the theory of Symon.

In Vavilov's exact treatment, the dimensionless parameter κ is introduced, and it is shown that for $\kappa << 1$ the fluctuations are large, while for $\kappa >> 1$, the fluctuations are negligible and the normal Gaussian shape of the total energy loss distribution is valid:

$$\kappa \equiv 0.150 \frac{(SZz^2)}{(A)} \frac{(1-\beta^2)}{(\beta^4)}$$, where

S = thickness of detector in g/cm^2,

Z = atomic number of detector material,

A = atomic weight of detector material,

z = charge on incident particle,

β = speed of incident particle ÷ speed of light in vacuum;

κ may be thought of as a measure of the ratio of the total energy loss to the maximum possible energy loss in a single collision, i.e., an estimate of the number of large-energy-loss collisions suffered by the particle in passage.

The purpose of our investigation is to verify experimentally the Vavilov theory over the whole range of κ, and to determine its implications in semiconductor detector studies of energetic charged-particle beams. We will not treat other sources of energy loss fluctuations, such as channeling.

Method

In a previous paper[7] we have described the advantages of lithium-drifted silicon semiconductor detectors for this work, the general method used, and the results of several preliminary experiments. In the preliminary experiments we found significant deviations between the theoretical energy-loss distributions and those which we measured. We surmised that these discrepancies were due to edge effects in our detectors, i.e., the sensitive thickness is slightly less at the edges than at the center area, and some particles pass through at the edges without "seeing" the full detector thickness. In order to correct this geometrical problem in this series of experiments, we used another smaller detector as a coincidence gate to eliminate all pulses due to particles passing through the edges of the "analyzing" detector. A block diagram of the experimental setup is shown in Fig. 1.

Results

We have performed a series of ten experiments at the 184-inch synchrocyclotron, using 730-MeV protons and 910-MeV alpha particles, covering the range of κ from 0.0033 to 1.02. The results of three typical experiments are shown in Figs. 2, 3, and 4. Figure 2 is a plot of the data from 730-MeV protons passing through a silicon detector with depletion thickness 0.66 g/cm^2, yielding $\kappa = 0.0338$. The solid curve is a plot of the Vavilov theoretical distribution as computed from the program of Seltzer and Berger.[8] Figure 3 is a plot of the data from 910-MeV α particles passing through a detector of thickness 0.413 g/cm^2, yielding $\kappa = 0.638$. Figure 4 is a plot of the data from 730-MeV protons passing through a detector of thickness 0.0645 g/cm^2, yielding $\kappa = 0.0033$.

Discussion

Agreement between measured energy-loss distributions and the theory is good in Figs. 2 and 3. Figure 2 is typical of what may be called the Landau spectrum, occurring at small κ values. The distribution is very asymmetrical, with a long high-energy-loss "tail" and a broad peak around the most probable energy loss, which is significantly less than the mean energy loss. Figure 3 is typical of intermediate values of κ, i.e., $\kappa \approx 1$. The distribution is very similar to the "expected" Gaussian, but with slight asymmetry, and the most probable energy loss is slightly less than the mean.

In Fig. 4 there is considerable disagreement between experiment and theory; the measured distribution is much broader than the theoretical. Upon closer examination, however, we find that the full width of the theoretical distribution at half maximum (FWHM) is 29 keV, while the inherent FWHM resolution of the measuring system at room temperature is approximately 40 keV. Adding these two quantities in quadrature yields an expected value of 49.5 keV; this is in good agreement with the measured value. Thus physical resolution limitations on our present measuring system prevent direct verification of the theory in this region of very small κ. Experiments are now in progress, using a system with improved resolution gained by cooling the detectors and using special low-noise electronics as developed by Goulding et al. [9]

Work is continuing on several other aspects of this problem. We are working on the tabulation of our findings into a form which will be convenient and useful to future experimenters.

Acknowledgments

We are obliged to Fred Goulding and Don Landis for help with electronics, Bob Lothrop for detectors, Jerry Howard and Dave Love for cyclotron operation, and Vic Brady for computer programming. This work was supported by the National Aeronautics and Space Administration and the U. S. Atomic Energy Commission. Mr. Maccabee wishes to thank the Atomic Energy Commission for continued fellowship support.

References

1. L. Landau, J. Phys. USSR 8, 201 (1944).

2. K. R. Symon, Ph. D. Thesis, Harvard University, 1948, summary in High Energy Particles (B. Rossi) Prentice-Hall, New York, 1952, p. 32.

3. P. V. Vavilov, Zh. Experim. i Teor. Fiz. 32, 920 (1957); English transl: Soviet Phys. JETP 5, 749 (1957).

4. T. J. Gooding and R. M. Eisberg, Phys. Rev. 105, 357 (1957).

5. W. Rosenzweig and H. H. Rossi, Statistical Fluctuations in the Energy Loss of 5.8 MeV Alpha Particles Passing Through an Absorber of Variable Thickness, Columbia Radiological Research Laboratory Report NYO-10716, Nov. 1963 (unpublished).

6. G. Grew, IEEE Trans. NS-12 [1], 308 (1965).

7. H. Maccabee and M. Raju, Nucl. Instr. and Methods 37, 176 (1965).

8. S. Seltzer and M. Berger, in Studies in Penetration of Charged Particles in Matter, NAS-NRC Pub. No. 1133, 1964, p. 187 ff.

9. F. S. Goulding, Semiconductor Detectors for Nuclear Spectrometry, Lawrence Radiation Laboratory Report UCRL-16231, July 1965 (unpublished), 87 ff.

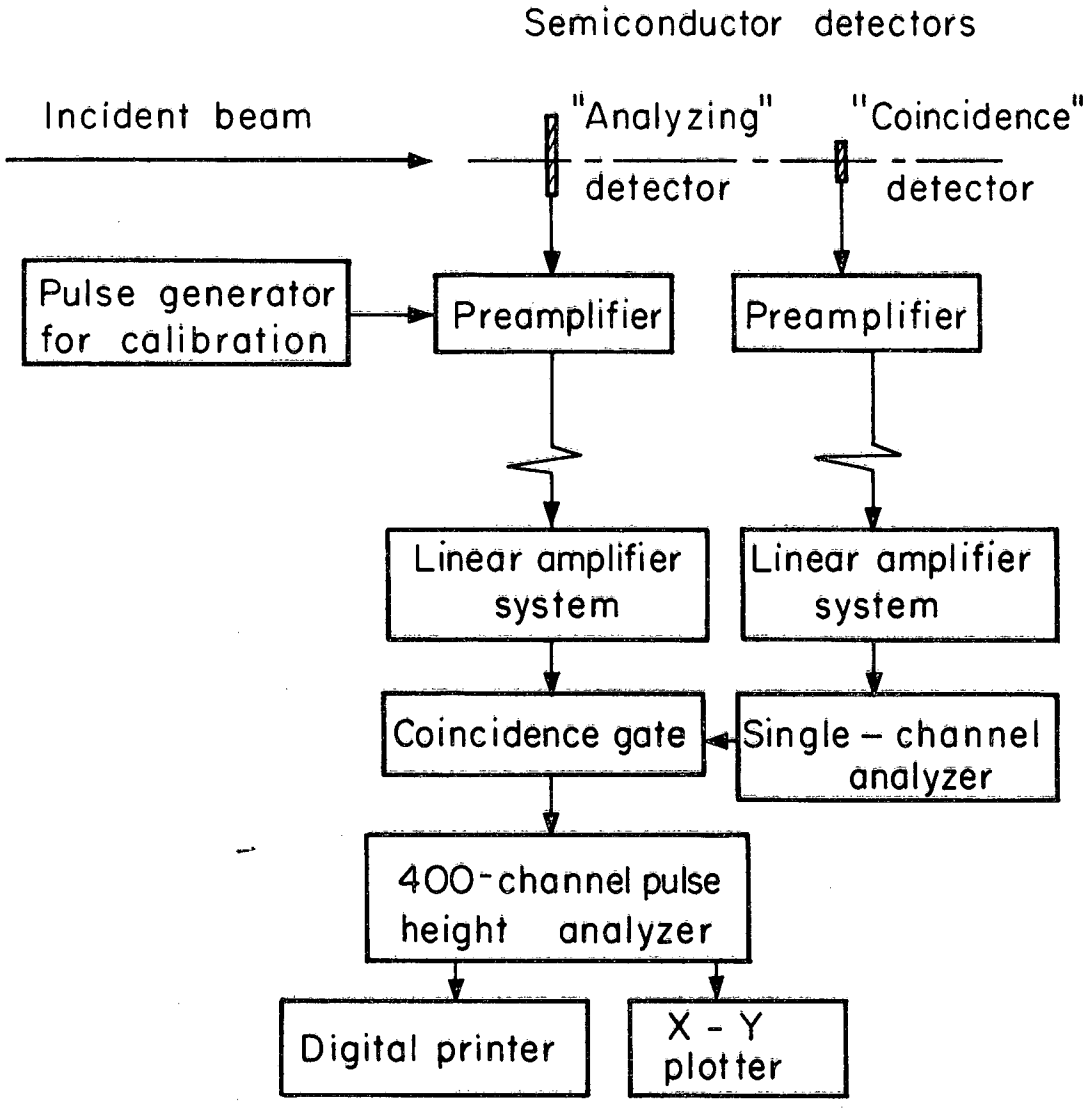
Figure Captions

Fig. 1. Block diagram of experimental setup.

Fig. 2. Energy-loss probability, 730-MeV protons in 0.66-g/cm^2 silicon; $\kappa = 0.0338$.

Fig. 3. Energy-loss probability, 910-MeV α particles in 0.413-g/cm^2 silicon; $\kappa = 0.638$.

Fig. 4. Energy-loss probability, 730-MeV protons in 0.0645-g/cm^2 silicon; $\kappa = 0.0033$.



BLOCK DIAGRAM OF EXPERIMENTAL SYSTEM

MUB-9083

Fig. 1

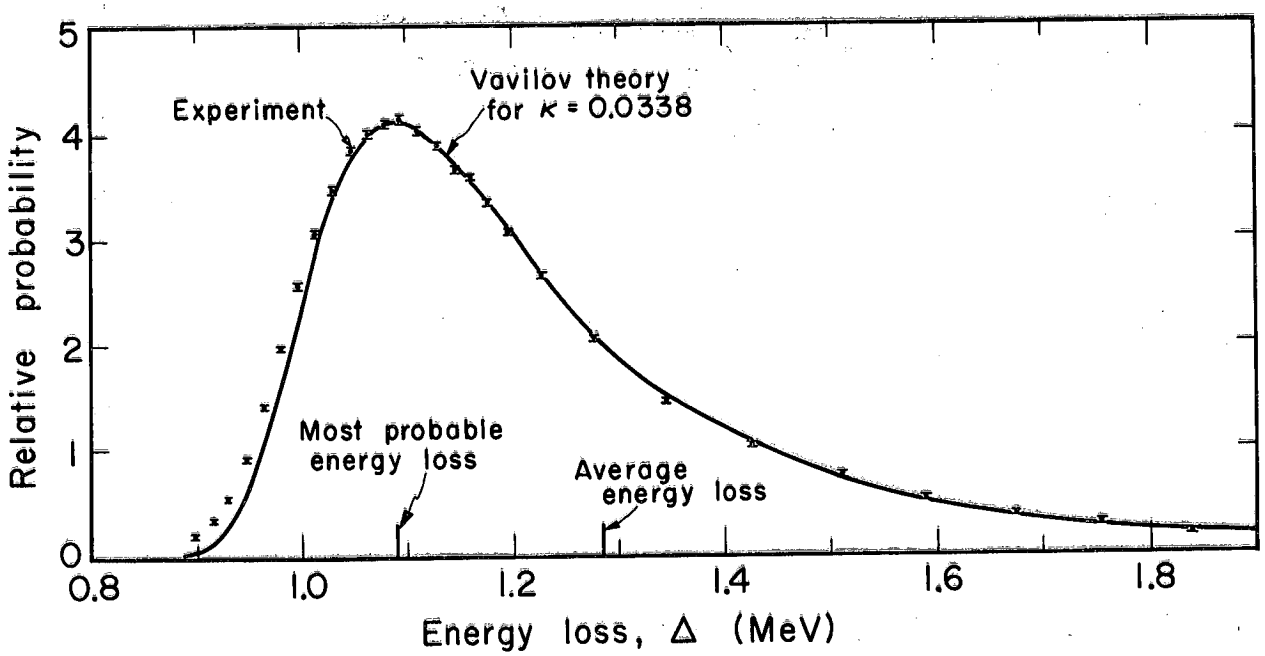
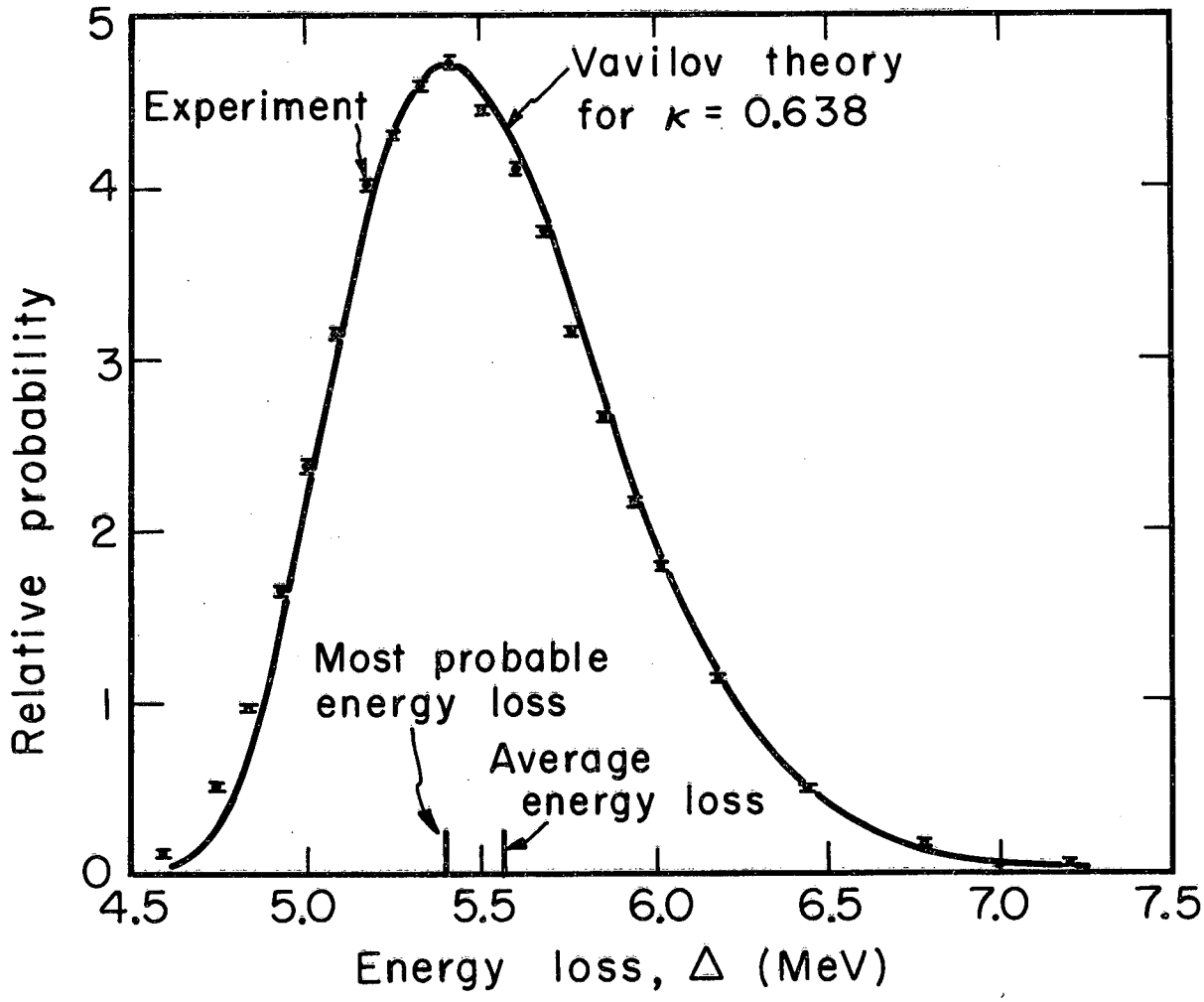

Relative probability
Energy loss, Δ (MeV)
Experiment
Vavilov theory
for κ = 0.0338
Most probable
energy loss
Average
energy loss
0
1
2
3
4
5
0.8
1.0
1.2
1.4
1.6
1.8
MUB-9086

Fig. 2



MUB-9084

Fig. 3

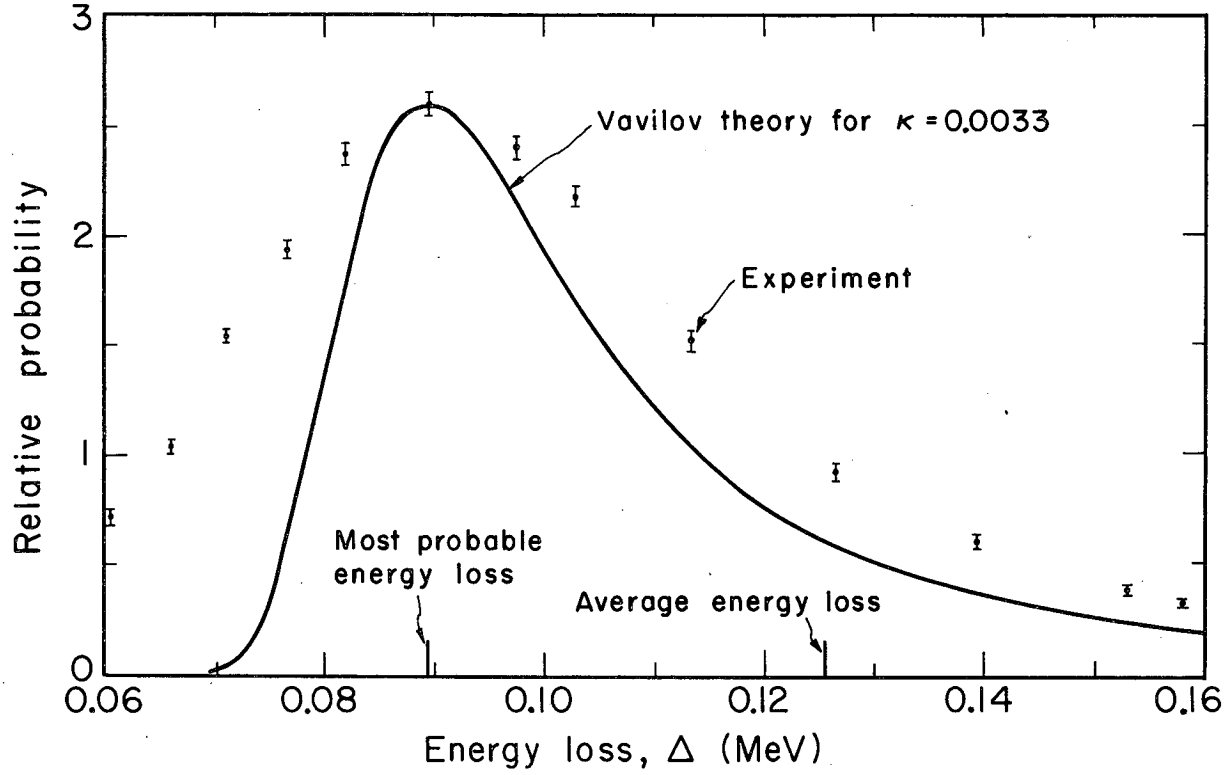

Relative probability
3
2
1
0
0.06
0.08
0.10
0.12
0.14
0.16
Energy loss, Δ (MeV)
Vavilov theory for κ = 0.0033
Experiment
Most probable energy loss
Average energy loss
MUB-9085

Fig. 4

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.