STRUCTURE IN THE KINETIC ENERGY SPECTRUM OF FRAGMENTS FROM THERMAL-NEUTRON-INDUCED FISSION OF U^{235}†

W. M. Gibson
Bell Telephone Laboratories, Murray Hill, New Jersey

and

T. D. Thomas and G. L. Miller
Brookhaven National Laboratory, Upton, New York
(Received June 19, 1961)

We have observed fine structure in the kinetic energy spectra of the heavy fragments from thermal-neutron-induced fission of U^{235}. This fine structure in the energy spectra is reflected as fine structure in the calculated fission-mass-yield distribution.

A target of 5 $\mu g/cm^2$ of U^{235} evaporated onto a 15-$\mu g/cm^2$ backing of VYNS film was placed between two 1.5-cm^2 p-n junction semiconductor particle detectors 5 cm apart. The target, counters, and integrating preamplifiers were enclosed in an evacuated aluminum can, which was lowered into the thermal column of the Brookhaven graphite research reactor. The pulses from the preamplifiers were further amplified by linear amplifiers whose outputs were fed into a coincidence circuit and into the two axes of a 64×64 two-dimensional pulse-height analyzer.[1] The pulse-height analyzer was triggered by the coincidence circuit and, therefore, recorded only those events in which a fission fragment entered each counter within the resolving time of the coincidence circuit (~0.1 μsec).

Two separate experiments were performed. In the first experiment, counters made by diffusion of phosphorus into 100-ohm-cm p-type silicon were used at a reverse bias of 100 volts. The coincidence counting rate was 2400 fissions/minute, and a total of 1.66×10^6 fissions was recorded. In the second experiment, the counters were of 300-ohm-cm silicon biased at 100 volts. Because there was evidence for a small low-energy tail on the kinetic energy spectra in the first experiment, two Plexiglas collimators were used in the second to keep the fission fragments from hitting the edges of the counters. The coincidence counting rate was 500 fissions/minute with a total of 6.1×10^5 fissions. Summation of the mass spectra over the total kinetic energy range of 70 Mev to 250 Mev gave a peak-to-valley ratio of 370/1.

Figure 1 shows the very pronounced structure in the energy spectra of heavy fragments in coincidence with light fragments of greater than 100 Mev. The energy channels are about 1 Mev wide in both directions. Stein's time-of-flight data have been used to calibrate the energy scale.[2] Recent time-of-flight measurements on thermal-neutron fission of U^{235} by Milton[3] show essentially the same structure. We observed no structure in the spectra of the light fragments nor in the spectra of heavy fragments in coincidence with light fragments of less than about 100 Mev.

The fission yield and average total kinetic energy as a function of mass number calculated from the

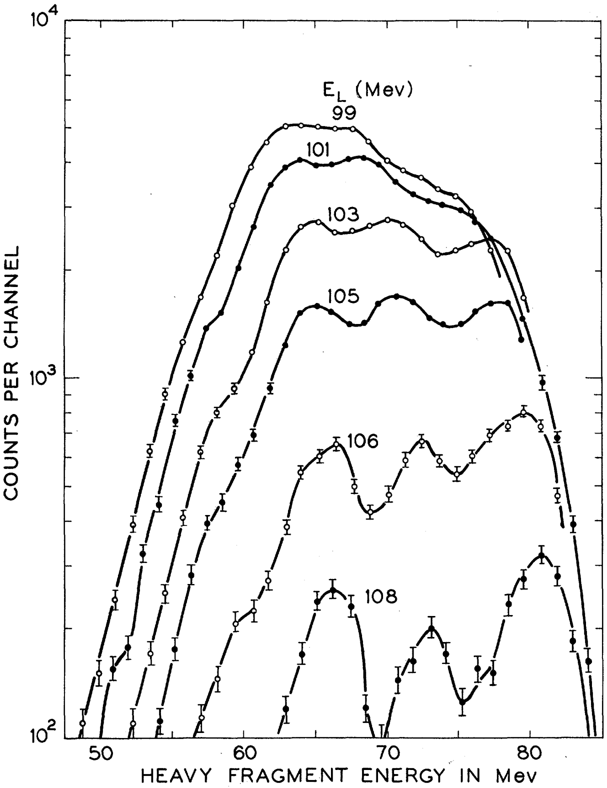

FIG. 1. Spectra of heavy fission fragments in coincidence with given light fragment energies, E_L. The open points and broken curves correspond to a heavy fragment into counter A and a light fragment into counter B; the closed points and unbroken curves to the reverse.

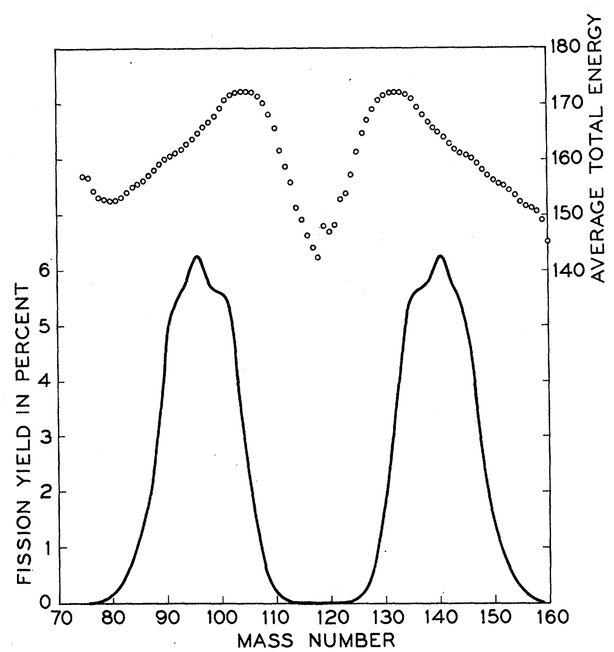

FIG. 2. Fission yield and average total kinetic energy as a function of mass number.

experimental data are shown in Fig. 2. Except in the regions of mass 100 and mass 134, the mass-yield data are in good agreement with the data obtained by Milton, who used the time-of-flight technique.[4] The kinetic energy curve falls somewhat lower than does Milton's, the difference being due to a difference between the time-of-flight measurements of Milton and those of Stein.[2]

The two shoulders on the mass-yield curve occur at light fragment masses of 92 and 101 and the peak occurs at light mass 96; the maxima in the curves of Fig. 1 correspond to light fragment masses of 91, 96, and 101. Thus, the structure in the mass-yield curve appears to be related to the structure in the kinetic energy spectrum. Mass-yield curves for specific values of the total kinetic energy differ from the summed curve of Fig. 2 in that they are narrower and in general do not show the fine structure apparent in Fig. 2. The structure in the total mass distribution arises from the fact that the mass-yield curves for different total kinetic energy tend to fall into three groups. For total kinetic energies less than 162 Mev, the most probable light fragment mass number is about 92; for energies between 164 and 171 Mev, about 96; and for energies greater than 173 Mev, about 101.

The highest energy peaks in the curves shown in Fig. 1 occur at energies corresponding to a heavy mass of about 135, which may be associated with the closed shells of 82 neutrons and 50 protons. However, there is no obvious correlation between closed shells and the other two peaks which correspond to heavy fragment masses of about 140 and 145 (or light masses of 96 and 91).

We have conducted similar measurements on the spontaneous fission of Cf^{252}. An experiment in which 6×10^5 fissions were recorded showed that any fine structure that may exist in the kinetic energy spectrum of Cf^{252} is much less pronounced than in the thermal neutron fission of U^{235}.

We are pleased to acknowledge the assistance of C. A. Boulin, who constructed the preamplifiers, and T. C. Madden, who made the counters and helped design the apparatus.

---

†Research was performed in part under the auspices of the U. S. Atomic Energy Commission.

[1]R. L. Chase, Brookhaven National Laboratory Report BNL-3838, 1958 (unpublished).

[2]W. E. Stein, Phys. Rev. 108, 94 (1957).

[3]J. C. D. Milton and J. S. Fraser, following Letter [Phys. Rev. Letters 7, 67 (1961)].

[4]J. C. D. Milton, quoted by G. C. Hanna, Proceedings of the International Conference on Nuclear Structure, Kingston, Canada, edited by D. A. Bromley and E. W. Vogt (University of Toronto Press, Toronto, 1960), p. 866.