EXPERIMENT 26

Fission Fragment Energy Loss Measurements from ^{252}Cf

EQUIPMENT NEEDED FROM EG&G ORTEC

Heavy-Ion Detector Model F-025-300-60
5-μCi ^{252}Cf Fission Oil and Source Kit SK-1A
142B Preamplifier
Bin and Power Supply
575A Amplifier
428 Detector Bias Supply
480 Pulser
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
Mechanical Pump
Model 3C52 Fission Chamber with Rotating Foil Wheel
Foil Set MC252
Oscilloscope
ORC-26 Cable Set

Introduction

In 1938 O. Hahn and F. Strassman discovered fission. In these studies they bombarded uranium with neutrons and produced nuclides which were chemically indistinguishable from elements in the middle range of the periodic table. Later scientists realized that the energetics of this process could be used as a power source. Theoretically, the fission process is not as well understood as most other nuclear reactions. Nevertheless, because of the energy potential of this process it has received more attention than any other nuclear reaction. As fossil fuel supplies are used the world is, and will continue to be, dependent on fission as a source of energy until alternate dependable sources such as fusion, solar, etc. are developed.

The advent of the high-flux isotope reactor has given a wealth of heavy isotopes that decay by spontaneous fission. ^{252}Cf is now readily available from commercial vendors as a fission foil source and an ideal candidate to be used in the study of the fission process.

Figure 26.1 shows a production diagram for ^{252}Cf. It is necessary to have a high-flux reactor to produce ^{252}Cf. Most of the species shown in Fig. 26.1 would rather decay to an appropriate daughter than absorb a neutron. The high-flux isotope reactors produce such a high neutron flux that absorption occurs before the isotope can decay. Thus ^{252}Cf is ultimately produced. Table 26.1 shows some of the physical properties of ^{252}Cf. Figure 26.2 shows a typical spectrum that will be measured in the laboratory for this experiment. If the kinematics of this fission are studied there is ~200 MeV available to the fission products. Conservation of momentum will give the light group about 30% more energy than the heavy group.

Table 26.1. Physical Properties of ^{252}Cf.

Alpha particle energy	:	6.12 MeV
Effective half life	:	2.65 years
Alpha decay half life	:	2.73 years
Spontaneous fission half life	:	85.5 years
Gamma emission rate	:	1.37×10^7 photons/μg
Specific activity	:	500 μCi/μg
Average neutron energy	:	2.35 MeV
Average neutrons per fission	:	3.76
Neutron emission rate	:	2.34×10^6 neutrons/s/μg
Fission rate	:	6.2×10^5/s/μg

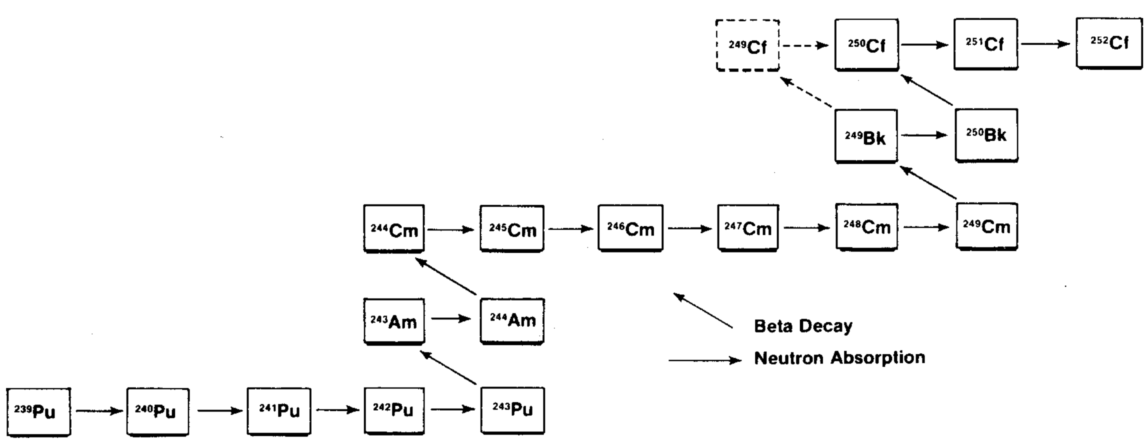

Fig. 26.1. Diagram Showing the Production of ^{252}Cf.

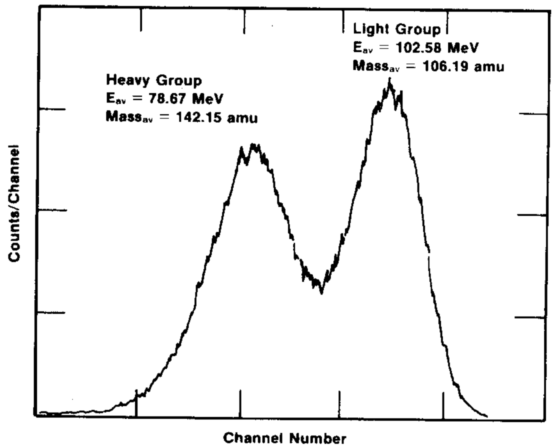

Fig. 26.2. Typical Pulse Height Spectrum for a Thin ^{252}Cf Fission Foil Source.

This energy difference is sufficient to easily separate the groups and perform energy loss measurements on both groups independently.

EXPERIMENT 26.1

Energy Calibration for Fission Fragments

In all of the experiments in this manual the energies measured were <10 MeV. In this experiment heavy ions will be measured having energies >100 MeV.* When the energy of a fast moving heavy ion is studied with a surface barrier detector, the measured number is always less than the theoretical value. This phenomenon is called the pulse-height defect. For alpha- and beta-particle measurement the effect is also present, but it is so insignificant that it is usually ignored. For heavy ions this pulse-height defect is produced by the following: entrance window effects, nuclear collision effects, and plasma effects. The entrance window effect is ~0.4 MeV for this experiment. It is accounted for by the dE/dx of the fission fragments in the gold entrance window of the detector. For 6-MeV alphas this loss would be ~4 keV. In the nuclear collision effect the fission fragment can interact with the nucleus with a fairly high probability. The average energy produced during this collision is lost to the production of electron hole pairs and a decrease in pulse height results.

The final decrease in pulse height is produced by the plasma effect. When the fission fragment enters the surface barrier detector it loses energy very rapidly, creating a dense cloud of electron hole pairs in a narrow region. This plasma tends to cancel out, for a short period of time, the electric field that is trying to separate the electron hole pairs and produce a pulse. During this short time a small fraction of the electron hole pairs can recombine with a subsequent loss in pulse height.

Many papers have been written on this phenomenon. Reference 9 is a good summary of measurements in regard to this effect. For ^{252}Cf the average pulse height defect is 16 MeV for both the heavy and light fission products.

Procedure

1. Set up the electronics as shown in Fig. 26.3. There are four positions on the foil wheel. Place the three aluminum absorbers in three of these positions. Line up the remaining open port with the detector and source. Evacuate the chamber with the vacuum pump and apply the recommended bias.

2. Adjust the gain of the 575A Amplifier so the 6.12-MeV alpha from the source is being stored in the first quarter of the MCA. Record the position of the peak. Turn on the 480 Pulse Generator and enter a X10 with one of the attenuators. Set the pulse height dial at 612/1000. Normalize the pulse

*See Detector Manual for comments on detector damage rates for neutrons, etc.

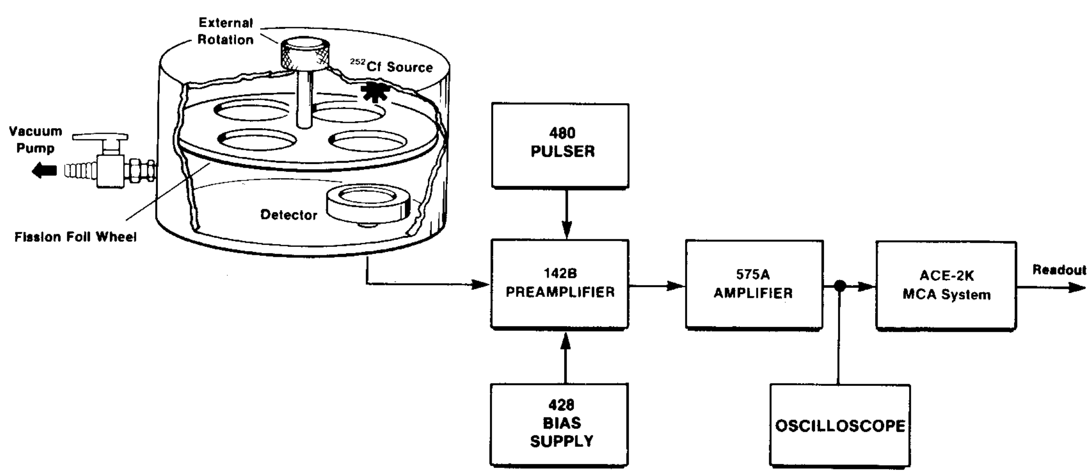

Fig. 26.3. Electronics Arrangement for Fission Fragment Energy Loss Experiment.

generator with the Cal control so that the pulser peak falls in the same channel as the 6.12-MeV alpha. This technique was carefully outlined in Experiment 4. The 480 is now calibrated for 10-MeV full scale. In order to change this calibration to 100-MeV full scale, it is only necessary to change the attenuator from X10 to X1. Now 500/1000 on the pulse height dial corresponds to 50 MeV, etc.

3. Set the 480 Pulser at 50 MeV and adjust the 575A Amplifier so the pulse is being stored in approximately channel 400. Make a calibration curve for 20, 40, 60, 80, and 100 MeV. Plot the calibration curve as in Experiment 4.

4. Turn off the 480 and accumulate a spectrum for the fission fragments from the ^{252}Cf source. The spectrum should resemble Fig. 26.2. Readout the MCA and plot the spectrum. Determine the centroid energy for both the light and heavy groups. What is your measured pulse height defect?

5. Rotate the foil wheel and place the thinnest aluminum foil between the source and the detector. Accumulate a spectrum and determine the centroids for the two peaks. From your calibration curve determine ΔE, the energy loss for both groups. Record these values in a data table as ΔE (measured) for both the light and heavy groups. Continue for the rest of the aluminum foils in the absorber kit. Your data table should also have an entry for ΔE (theoretical) for each foil and each group. This value is calculated in the exercise that follows.

6. Turn the bias down and carefully let the system up to air. Remove the aluminum absorbers and replace them with the copper absorbers. Pump back down, turn the bias on, and repeat step **5** for these copper foils.

EXERCISES

Figure 26.4 shows the mass distribution of the fission fragments from ^{252}Cf. To compare our experimental data to the theory, assume that the light fragment has a mass of 106 amu and use the theoretical dE/dx tables for $^{106}_{46}$Pd. For the heavy mass the average is 142 amu, and therefore, the dE/dx for $^{142}_{60}$Nd will be used. From ref. 6, the dE/dx (theory) of $^{106}_{46}$Pd at 102.58 MeV is 44.05 MeV-cm^2/mg.

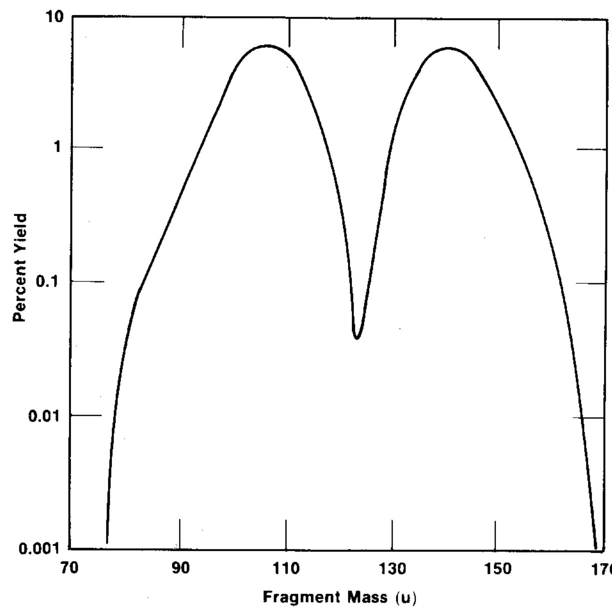

Fig. 26.4. Mass Distribution of Fission Fragments for ^{252}Cf.

Assuming that the light mass passes through a 0.250 mg/cm^2 aluminum foil, the theoretical energy loss would be:

$$\Delta E \text{ (theory)} = 44.05 \text{ MeV-cm}^2/\text{mg} \times 0.250 \text{ mg/cm}^2 = 11.01 \text{ MeV}.$$

These procedures were covered in Experiment 5. Calculate $\Delta E/\Delta x$ (theory) for the rest of the aluminum foils and all of the copper foils. Record these values in your data table and calculate the percentage difference between your experimental values and the theoretical calculations. The dE/dx (theory) values for the fragment and foils used in this experiment are shown in Table 26.2.

Table 26.2. dE/dx (theory) (from ref. 6).

Fragment	Energy	dE/dx (theory) Aluminum	dE/dx (theory) Copper
Light $^{106}_{46}$Pd	102.58	44.05 MeV-cm^2/mg	30.77 MeV-cm^2/mg
Heavy $^{142}_{60}$Nd	78.67	43.99 MeV-cm^2/mg	28.6 MeV-cm^2/mg

Note of Credit This experiment was developed primarily by Professor Dollard Desmarais of the University of Alberta, Canada and the author. A detailed "Fission Fragment Energy Loss" experiment will appear in the *American Journal of Physics* in the summer of 1984.

References

1. G. Bertolini and A. Coche, Eds, *Semiconductor Detectors*, Sections 4.1.1 and 4.2.1 to 4.2.4, American Elsevier Publishing Co., New York (1968).

2. G. F. Knoll, *Radiation Detection and Measurement*, John Wiley and Sons, New York (1979).

3. H. W. Schmitt and F. Pleasonton, *Nucl. Instrum. Methods* **40**, 204 (1966).

4. S. Parker and H. N. Steiger-Shafrin, *Nucl. Instrum. Methods* **91**, 557 (1971).

5. H. L. Adair, *Nucl. Instrum. Methods* **100**, 467 (1972).

6. L. C. Northcliffe and R. F. Schilling, *Nuclear Data Tables* **A7**, 233, Academic Press, New York (1970).

7. H. Henschel, *et al., Nucl. Instrum. Methods* **190**, 125 (1981).

8. "Heavy Ion Spectroscopy with Silicon Surface Barrier Detectors," *EG&G ORTEC Application Note AN-40.* Available from EG&G ORTEC.

9. E. C. Finch and A. L. Rodgers, "Measurements of the Pulse Height Defect and its Mass Dependence for Heavy Ion Silicon Detectors," *Nucl. Instrum. Methods* **113**, 29 (1973).