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Energy losses of ^{252}Cf fission fragments in thin foils

G.N. Knyazheva [a,c], S.V. Khlebnikov [a,b], E.M. Kozulin [c], T.E. Kuzmina [b], V.G. Lyapin [d], M. Mutterer [e], J. Perkowski [f], W.H. Trzaska [a,d,*]

[a] Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40014 Jyväskylä, Finland
[b] V.G. Khlopin Radium Institute, St. Petersburg 194021, Russia
[c] Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Moscow region, Russia
[d] Helsinki Institute of Physics, P.O. Box 35, FIN-40014 Jyväskylä, Finland
[e] Institute of Nuclear Physics, Darmstadt University of Technology, Schlossgartenstrasse 9, D-64289 Darmstadt, Germany
[f] University of Lodz, Nuclear Physics Division, Pomorska Street, 149/153, 90-236 Lodz, Poland

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Abstract

The stopping power of fission fragments from ^{252}Cf(sf) has been measured in thin foils of C, Ni, Au, Al_2O_3 and Mylar as a function of fragment mass and energy. The chosen stopping materials are frequently used as the backing of sources and targets or entrance windows of gas detectors. The experimental setup allowed registration of velocities of two fission fragments and energy of one of them. In this way fragment masses could be unambiguously determined and the pulse-height defect of the silicon detector verified. The measured stopping power data for fission fragments cover masses between $A = 101$ and $A = 148$. The results are compared with semi-empirical predictions of SRIM 2003 code, LSS theory and theoretical calculation by Sigmund (PASS code). The best representations of the data are achieved by a semi-empirical formula based on classical Bohr theory. The formula was successfully tested also on the available data for Ar, Ca, Kr, Xe and Au ions in the energy range 0.2–6 MeV/u slowing down in carbon, nickel and gold.

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1. Introduction

Interaction of energetic heavy ions penetrating through matter is relevant to many areas of basic and applied nuclear physics [1]. Much research effort was put to achieve accurate theoretical description of the complex process of atomic collisions and to measure with sufficient precision the resulting energy losses of light and heavy ions in various elements and compounds [2]. Fragments originating from fission of actinides deserve a special attention among the other heavy projectiles. They are important in both basic and applied research, are neutron rich ($Z/A \approx 98/252$), relatively heavy ($70 \leqslant A \leqslant 160$) and have fairly low velocities ($0.4 \leqslant E/A \leqslant 1.3$) MeV/u. Although fission fragments (FF) were widely used already in the pioneering studies of atomic collisions, the scope and quality of the measured stopping power data are rather limited and the predictive power of the available semi-empirical evaluation is not yet satisfactory [3].

Most experiments studying nuclear fission require precise measurement of energy and velocity of FF. The precision of such measurements is limited by the uncertainty of corrections for energy loss of FF in target material, detector windows, dead layers, etc. Already in very thin layers of any solid material (<1 μm) the energy loss of

* Corresponding author. Address: Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40014 Jyväskylä, Finland. Tel.: +358 14 260 2409; fax: +358 14 260 2351.
E-mail address: trzaska@phys.jyu.fi (W.H. Trzaska).

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FF is remarkably high and has to be accounted for to obtain the initial energy of the measured fragment. Usually the energy losses of FF for a given effective thickness of the stopping material are calculated from the Lindhardt, Scharff and Schiøtt (LSS) theory [4] or taken from one of the existing compilations, e.g. SRIM 2003 code by Ziegler et al. [5].

In practice, the lack of reliable energy loss data and uncertainties in the thickness of substrate material force experimentalists to treat the energy loss of FF as an adjustable parameter in the equations used for processing of the experimental data [6]. This, in turn, increases the error of the measured velocities and energies of FF and, subsequently, of all the derived values such as mass and total kinetic energy (TKE) distributions [7].

In this work we have measured stopping power of FF from ^{252}Cf spontaneous fission (sf) in thin foils of C, Ni, Au, Al_2O_3 and Mylar. These materials are frequently used as the backing of sources and targets and as entrance windows of FF detectors.

2. Experiment

2.1. Experimental set-up

A simple way to measure energy loss of FF is to register the characteristic double-humped energy spectrum with and without the slowing-down foil. Subsequently, each spectrum is divided into sections with, for instance, both the light and heavy peak subdivided into three parts. Finally, for each part the mean energy is determined. As a result, a measurement with a single foil (and without it) yields six experimental points, each for a different mass and energy. Such experiments are meaningful despite their simplicity because the Cf fission fragment spectrum is very well known and there is a strict correspondence between the energy and the average mass of the fragment. Previous measurements of energy losses of FF from ^{252}Cf (see e.g. [8]) were done this way.

In the present work, to provide direct identification of the masses we have measured also the velocities of both FF. This allowed us also to determine directly the pulse-height defect (PHD) of our silicon detector for registration of FF. To eliminate the need of non-linear corrections to the measured energy losses as function of energy we have used only thin stopping foils. Typical energy loss was about 20% of the initial energy. In addition to providing a complete set of acquired data points, we give a semi-empirical formula that allows for a fair degree of extrapolation to other mass values and energies.

The experimental configuration is shown schematically in Fig. 1. It consists of the Cf source, three microchannel plate (MCP) time pick-off detectors and one energy detector. The stopping foils were fixed on the rotating holder designed for automatic changing of the foils in front of the silicon detector. One of the positions on the wheel has been left intentionally empty. It gave the possibility to measure the energies of FF not affected by the slowing-down media. A similar setup has been used by us previously [9] for dE/dx measurements. The main difference is the addition of the third microchannel plate (MCP) time pick-off detector, marked as MCP1 in Fig. 1. The third MCP detector was necessary for mass identification of the fragments, as explained in the next section. The time resolution of MCP detectors was very good. For instance, for ^{238}Pu α-particles we could reach 190 ps full width at half maximum (FWHM) of the TOF peak. For fission fragments the corresponding value was better than 100 ps. More information on our MCP detectors can be found in [9].

The energy detector was a silicon PIN diode $20 \times 20 \times 0.380$ mm^3. The PIN diode was biased to +120 V and operated in fully depleted mode. The energy resolution was 32 keV for 7687 keV α-particles from ^{226}Ra source. The

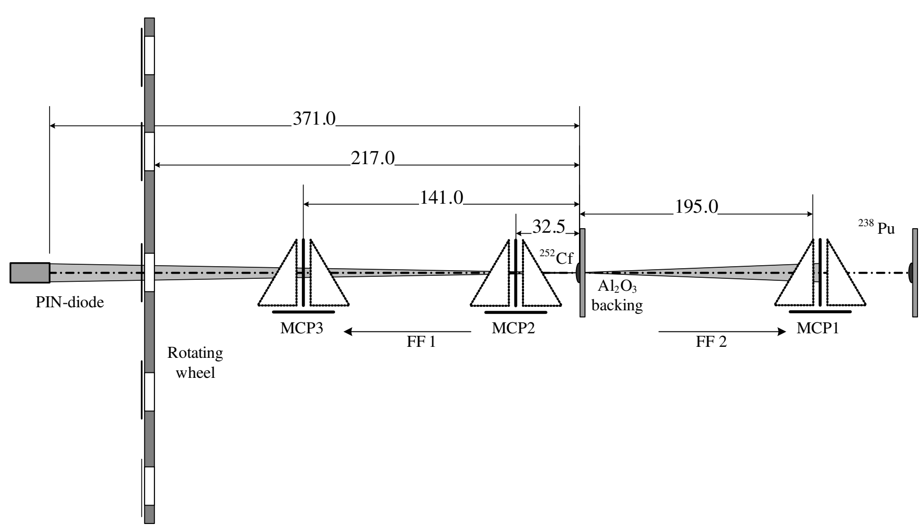

Fig. 1. Sketch of the experimental set-up to measure energy losses of ^{252}Cf fission fragments in thin foils. The indicated distances are in mm. The ^{252}Cf deposit is on the side of the source facing MCP2 side. The ^{238}Pu α-source was used for calibration.