similar to those outlined here might apply to other situations in which a parity-nonconserving gamma decay can compete with a highly inhibited, but parity-allowed, transition. However, they do not apply to the search for a parity nonconservation in the[12] 482-keV $M1$ transition in Ta^{181} where the $M1$ inhibition is not due to a K selection rule and it might be expected that $\mathcal{G}^2 \approx \mathcal{F}^2$.

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NEUTRON EMISSION IN ^{226}Ra PROTON-INDUCED FISSION*

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The average number of neutrons ν emitted as a function of m^*, the prompt-fragment mass, has been experimentally determined for 13-MeV proton-induced fission of ^{226}Ra. The trend of $\nu(m^*)$ is found to be similar to the familiar "sawtooth" shape observed in low-excitation fission.[1-4] The value of ν increases in the fragment mass range 82 to 122 amu, decreases rapidly in the range 123 to 134 amu, then increases slightly in the range 134 to 144 amu. The sharp drop does not occur at or near symmetry, but occurs in the mass region just below closure of the $Z = 50$ and $N = 82$ shells for neutron-rich nuclei. These results are qualitatively consistent with a previously suggested description of ^{226}Ra fission[5] involving liquid-drop-model considerations[6] for mass divisions in the region of symmetry (the central peak in the fragment mass distribution), and "fragment-shell" or "fragment-structure" considerations[7-9] for asymmetric mass divisions (peaks at ~89 and ~138 amu in the mass distribution). The results are also qualitatively consistent with a prediction by Terrell[7] based on the systematics of neutron emission in low-excitation fission.

Direct neutron-counting experiments of the kind required to determine neutron emission properties in fission would be difficult or impractical for medium- or high-excitation fission, because of the high backgrounds and low intensities characteristic of such experiments at partical accelerators. Thus an indirect method involving three-parameter correlation measurements of both fragment energies and one fragment velocity has been developed.[10,11]

In practice, the pulse amplitudes of both fission fragments in solid-state detectors and the time of flight of one of the fragments were measured and recorded event by event on punched paper tape. Details of the development, calibration, and properties of this method of determination of neutron emission in fission are given in Ref. 10. In the present work, the experiment was performed for ^{226}Ra proton fission and for ^{252}Cf spontaneous fission under essentially identical experimental conditions, as required for calibration. The number of events accumulated in the ^{226}Ra experiment was 1.2×10^5; 256 channels were used in each of the three parameters.

For the radium measurements, protons were incident on a thin deposit of radium bromide, about 50 μg/cm^2 thick, vacuum evaporated onto a carbon film about 20 μg/cm^2 thick. Protons of energy 13.0 MeV were obtained from the Oak Ridge tandem Van de Graaff accelerator. For the ^{252}Cf measurement, a source made by self-transfer onto ~70-μg/cm^2 thick nickel was used.

Two silicon surface-barrier detectors 4 cm^2 in area were used to detect the fragments. One detector was located 9.60 cm from the fission source and detected fragments which had passed through the carbon backing. The other detector was located 101.16 cm from the source and detected the unperturbed fragments. The relative sizes of the detectors and fissioning sources were such that for all fragments incident on the remote detector, the complementary fragment was incident on the near detector. The remote detector was located to detect fragments at an angle $\theta = 30°$ with respect to the proton beam.

Transformer coupling and associated circuits (time pick-off units) were used to produce the fast timing pulses; a time-to-pulse-height converter produced pulses whose amplitudes were proportional to the time interval between detector pulses.

Analysis of the data proceeded according to the formulation of Ref. 10. The absolute energy- and time-calibration constants for the radium experiment were obtained from a three-parameter ^{252}Cf spontaneous-fission experiment carried out with the same detectors and under the same operating conditions. The method of analysis makes use of three principles commonly used in fission kinetics experiments: (1) If neutron emission from the fragments satisfies the condition $\langle\cos\theta_{\rm cm}\rangle = 0$, where $\theta_{\rm cm}$ = center-of-mass angle of neutron emission, the average final fragment velocity (corresponding to a given initial fragment velocity) is essentially equal to the initial fragment velocity. (2) Under the same conditions of neutron emission and for given initial fragment mass and energy, the ratio of the average final fragment energy to initial fragment energy is essentially equal to the ratio of average final fragment mass to initial fragment mass. (3) Linear momentum is conserved for the pre-neutron-emission fragments. In addition, a method of determining complementary points (defined as points reflected about the line $E_1 = E_2$ in E_1-E_2 coordinates) was developed and incorporated[10] to make use of original data for complementary events in the analysis to obtain fragment neutron-emission properties.

Results giving $\nu(m^*)$, the average number of neutrons emitted as a function of prompt-fragment mass, and $\nu_T(m^*)$, the average total number of neutrons emitted as a function of fragment mass, are shown in Fig. 1 along with a smooth dashed curve representing the pre-neutron-emission mass distribution obtained in this experiment. The mass distribution is consistent with the distributions reported previously[5] for proton energies 11.0, 12.0, and 13.5 MeV.

Two sets of points are shown for $\nu(m^*)$: The open circles show the results obtained directly from the experiment, without corrections for dispersion shift. The solid points and curve show $\nu(m^*)$ corrected for this effect. Because of the small magnitude of these corrections, no correction was made in $\nu_T(m^*)$. Although the trends in $\nu(m^*)$ and $\nu_T(m^*)$ are quite definitely established, the uncertainty in absolute values is difficult to evaluate and may be as high as ~0.4 amu.

A number of features of these new results are of interest. For example, the effect of nuclear structure in the fragments, particularly of the closed $Z = 50$ and/or $N = 82$ shell configurations, is again evident, and appears to give rise to the sharp decreasing portion of the sawtooth shape of $\nu(m^*)$ as observed in low-excitation fission.[1-4,7]

The fact that the general sawtooth shape of $\nu(m^*)$ is maintained, even at moderate excitation energy (18.3 MeV in ^{227}Ac in the present case), is itself of interest. This observation is qualitatively consistent with the delineation of two modes of fission for ^{226}Ra(p, f) proposed previously.[5] In this description of radium fission, the asymmetric mass peaks are associated with "nuclear-structure" fission similar to that observed for heavier elements at low excitation energy, while the symmetric mass peak is associated with liquid-drop fission.[12]

The behavior of $\nu(m^*)$ may be taken as an

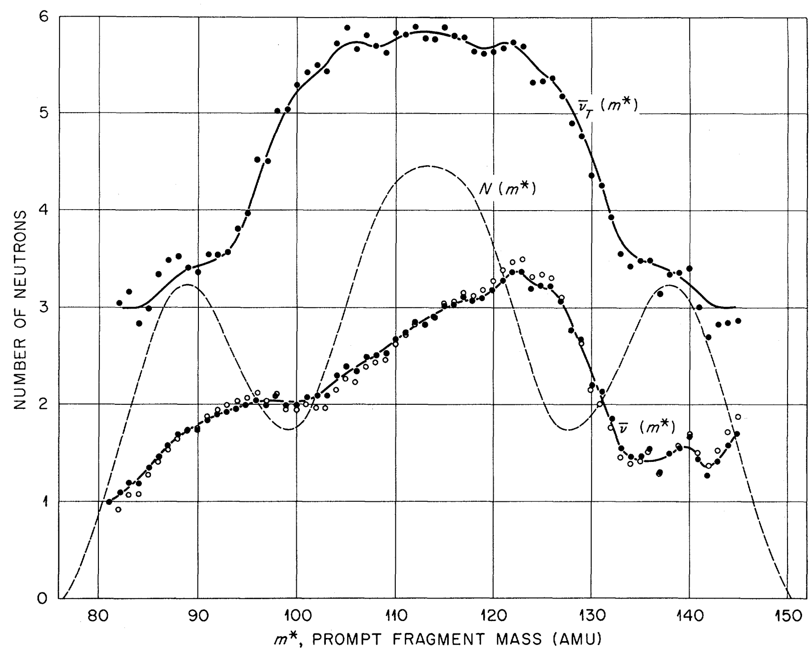

FIG. 1. Average number of neutrons emitted as a function of fragment mass in 13.0-MeV proton-induced fission of ^{226}Ra. Open circles show the average number of neutrons emitted from single fragments, uncorrected for dispersion shift. Closed circles (lower curve) show $\nu(m^*)$, corrected for dispersion shift. Upper curve shows $\nu_T(m^*)$, the total number of neutrons emitted as a function of fragment mass. (The small differences between the points and the symmetrized smooth curve provide an indication of the quality of the experiment.) The smooth dashed curve shows $N(m^*)$, the prompt mass distribution.

indication of the behavior of the single-fragment excitation energy. The generally smooth increase through the symmetric region (~105 to ~122 amu) is as predicted by the nonviscous liquid-drop model calculations of Nix and Swiatecki,[6] although the calculated slope is about one-half of the measured slope in this mass region.

Similarly, the shape of $\nu_T(m^*)$ in the region of symmetry may be taken as an indication of the behavior of the total excitation energy of the two fragments. The liquid-drop-model calculated in this case results in a constant value, to first order, in qualitative agreement with the observations shown in Fig. 1.

Even though the calculations and measurements are not in quantitative agreement, the general features of the functions in the region of symmetry are qualitatively reproduced. At the present stage, better agreement should perhaps not be expected.

The general shape of $\nu(m^*)$ as shown in Fig. 1 was also anticipated by Terrell[7] on the basis of systematics of neutron emission in low-excitation fission. In particular, the sharp decrease in the mass region below closed-shell configurations in the heavy fragment is qualitatively predicted on the basis of nuclear-structure effects in the fragments.

Other features of interest in the present results include, for example, the shallow minimum observed in $\nu(m^*)$, with respect to an otherwise smooth increase, in the region at ~100 amu. This dip could be caused by lower excitation energies associated with $Z = 40$ and $N = 64$ configurations. The slight extra stability of these particular configurations in fission fragments has been observed in semiemperical calculations of nuclear deformation parameters[9] based on low-excitation fission data.

It is also of interest that a fine-structure maximum appears to be present in $\nu(m^*)$ at ~123 amu, in approximately the same location as the general maximum of the curve. Fine-structure peaks at ~123 amu have been observed in the prompt mass distributions for ^{235}U, ^{239}Pu, and ^{241}Pu thermal-neutron fission.[13] There are other indications of fine structure in $\nu(m^*)$ and $\nu_T(m^*)$, the systematics of which are being studied.

In the results discussed here, we find evidence for the influence of nuclear-structure effects not only in the asymmetric mass divisions, but also in the near-symmetric mass divisions. Almost certainly a combination of liquid-drop and nuclear-structure considerations will be required in a more quantitative description of ^{226}Ra fission.

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