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Subthreshold Neutron-Induced Fission Cross Section of Am^{241}†

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The corona-type spark chamber has been adapted for detection of fission fragments and has been used as the detector for neutron-induced fission cross-section measurements of Am^{241}. Measurements were made over the neutron energy range from 0.032 to 80 eV. The ratio of average fission width to spacing is in good agreement with that predicted from the shape of the fast-neutron fission threshold. The number of effective fission channels obtained from an analysis of the distribution of fission widths was found to be 2.9±0.6 channels.

INTRODUCTION

The nucleus Am^{241} belongs to the group of nuclei which can be classified as nonfissionable by thermal neutrons. These nuclei are characterized by a fission threshold in the vicinity of 1 MeV where, within an energy interval of a few hundred keV, the fission cross section increases by orders of magnitude to a saturation value. This behavior is characteristic of barrier penetration and has been described as such by Hill and Wheeler.[1] They give an expression for the ratio of the average fission width to level spacing $\langle\Gamma_f/D\rangle$ as

$$2\pi\langle\Gamma_f/D\rangle=\frac{1}{1+\exp[2\pi(E_t-E)/\hbar\omega]} \quad (1)$$

for a single fission channel. In this expression E_t is the energy at which the fission cross section is half the saturation value and ω is a frequency characteristic of the fission barrier. The parameters of this relation can be determined by fitting this expression to the observed fast-fission threshold. It is then possible to predict the value of $\langle\Gamma_f/D\rangle$ in the region of epithermal neutron energies assuming that both the subthreshold fission and the fission in the neighborhood of the fast threshold are characterized by the same fission channel. Equation (1) predicts small cross sections in the epithermal region which nevertheless may be observable particularly in the neighborhood of large slow-neutron resonances.

Leonard[2] did the pioneering work in subthreshold fission studies. He studied subthreshold fission in Np^{237}, Pu^{240}, and Am^{241}. Conditions in these experiments restricted the measurements to a rather narrow energy interval so that no more than three resonances were directly studied in any single isotope. Additional data having higher statistical accuracy and covering a wider energy range would clearly be helpful to an understanding of subthreshold fission.

The experimental difficulties encountered in the measurement of small cross sections are associated with the problem of obtaining enough neutron flux to induce fission events at a rate well above the background arising from (1) spontaneous fission of the sample and (2) spurious counts from the pile-up of pulses from the natural alpha activity of the sample. The background due to spontaneous fission apparently can be overcome only by increasing the neutron source intensity. However, the background due to the natural alpha activity of the sample can be reduced by improvements in detectors allowing more effective discrimination against alpha particles. The technique usually employed is that of reducing the resolving time of the detector until the probability is very small that a sufficient number of alpha particles may add their pulse heights so as to exceed a bias level set for fission fragments. The gas scintillator[3] has been quite useful for this purpose. Effective discrimination against intense alpha activity by a different means has also been demonstrated with the corona-type spark chamber.[4] However, such a detector has not been previously used in fission cross-section measurements.

The present report describes a measurement of the subthreshold fission cross section of Am^{241} using the spark chamber as the fission fragment detector. A successful measurement on this nucleus should demonstrate the usefulness of such a detector for studies of subthreshold fission in highly alpha-active nuclei and also of thermally fissionable materials with half-lines as short as a few years.

THE DETECTOR

The sensitive element of the spark chamber is a semicylindrical channel with a wire positioned along the channel axis. A potential difference, which is enough to draw corona current in the presence of natural air at a pressure of about one atmosphere, is placed across the gap between the channel and wire. The stable equilibrium created by the corona current is not upset by the ionization resulting from the passage of an electron. Under proper adjustment the detector also can be made stable against discharge due to the much higher ionization density created by

† Work performed under auspices of U. S. Atomic Energy Commission.

[1] D. L. Hill and J. A. Wheeler, Phys. Rev. **89**, 1102 (1953).
[2] B. R. Leonard, Jr., Nuclear Physics Research Quarterly Report HW 59126, 1959, p. 3 (unpublished).
[3] C. Eggler and C. M. Huddleston, Nucleonics **14**, 34 (1956).
[4] C. D. Bowman and R. W. Hill, Nucl. Instr. Methods **24**, 213 (1963).

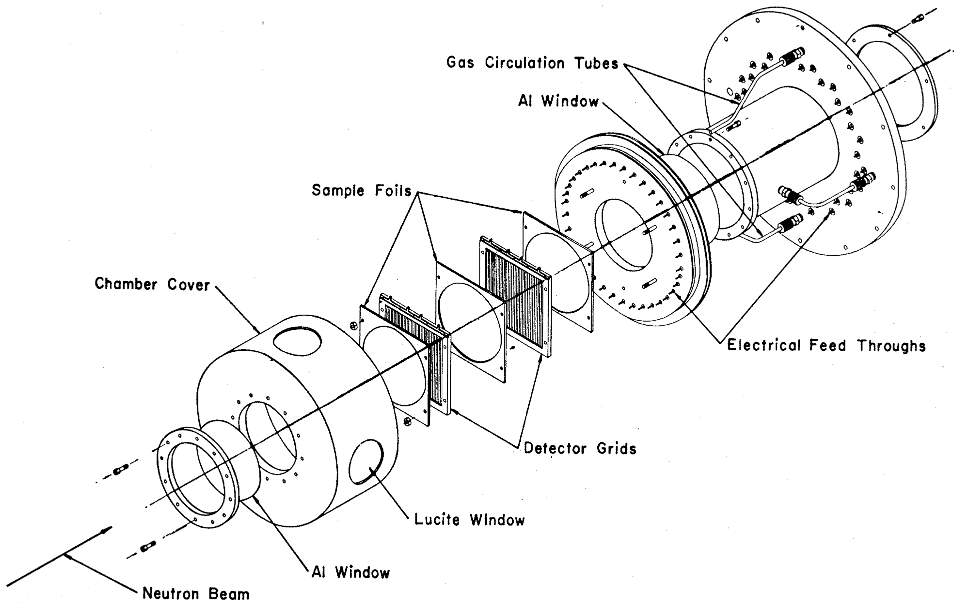

FIG. 1. An exploded view of the fission chamber.

the passage of a single alpha particle, while still undergoing breakdown due to the even higher ionization density created by the passage of fission fragments. Under these conditions alpha particles will not induce a spark unless a number of them are emitted at almost the same time and, in addition, traverse the same point in space so that the ionization density at that point may equal or exceed that due to a fission fragment. This spatial discrimination against alpha particles is a unique feature of the spark chamber and makes it especially suitable for this experiment.

When a spark is initiated, a potential change of about 2500 V occurs across the gap. This large signal rises in 5 nsec or less. Only attenuators are necessary between the detector and the recording device, thus eliminating the need for the complicated electronic equipment needed with other types of detectors. The almost complete insensitivity of this detector to photons[4] was also especially useful in this experiment, as explained below.

The basic detector units were adapted from the design developed by Singh and Saha.[5] Each of two 0.025-cm-thick foils of copper were corrugated into 32 adjacent 0.32-cm-diam channels. The corrugated foils were then glued back-to-back onto a supporting nonconducting frame. Wires of 0.0125 cm diameter were stretched along the axis of each cylindrical corrugation and held in position by clamps at both ends on the frames. The wires of the 32 channels were divided into four groups of eight each and all wires within a group were connected together electrically. A tie post was provided for each group.

The arrangement of these detector units in the fission chamber is shown in Fig. 1. The detector units were sandwiched between foils that were electroplated on both sides with Am^{241} oxide. The sandwich containing four detector units and five sample foils was attached to the base plate with four studs. The sandwich was 3.5 cm thick. Electrical connections for each group of wires were made to the electrical feedthroughs in the base plate. The chamber cover was then placed over the stack to form a vacuum-tight chamber with provision for gas circulation. Aluminum windows, each 0.081 cm thick, were provided at the front and back of the detector. The neutron beam passed down the axis of the cylindrical chamber. Load resistors and pulse divider circuitry was then added in the space between the two sets of electrical feedthroughs shown in Fig. 1. The entire chamber was then enclosed in another container to meet the Laboratory's safety standards for highly radioactive materials.

The samples were 0.012-cm-thick nickel foils electroplated on both sides with Am^{241} oxide to a thickness of 0.2 mg/cm^2. The chamber contained a total of about 200 mg of Am^{241}, which gave 2.5×10^{10} alpha particles per sec. The isotopic composition of the sample, which was almost pure Am^{241}, is given in Table I.

The spark chamber was filled with "water-pumped" air at a pressure of 48 cm of Hg. Bottled air was used in preference to the ordinary atmosphere to eliminate fluctuations in background and efficiency due to varia-

TABLE I. Isotopic composition of the sample.

Isotope	%
Am^{241}	99.95
Pu^{239}	<0.05
Pu^{240}	<0.005
Pu^{241}	<0.0005

[5] G. Singh and N. K. Saha, Nucl. Instr. Methods 13, 22 (1961).

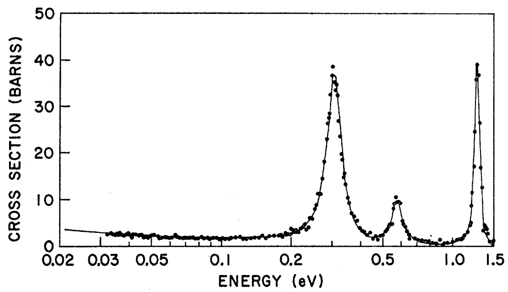

FIG. 2. The fission cross section of Am^{241} in the energy interval from 0.032 to 1.5 eV. The solid line is the sum of three Breit-Wigner single-level fits to the data.

tions in the air humidity. The air was circulated slowly to prevent the accumulation of a high concentration of ozone in the fission chamber. A potential difference of 2480 V was applied across the 0.16-cm gap between the wires and the copper channels. The background under these conditions was found to be about five sparks per min. It was not clear how this background should be divided between that due to the alpha activity and that arising from the spontaneous sparking within the chamber, which would have occurred even in the absence of the alpha activity. Since considerable difficulties with spontaneous sparking were encountered before the chamber was assembled, it is felt that these effects contributed the major portion of the background. In the more recently constructed detector units small changes in the design have reduced this problem considerably.

The efficiency of the detector was found to be between 5 and 10%, which was well below the 30% expected on the basis of the pilot model.[4] It is hoped that the reduction of the spontaneous breakdown in future detector units will allow operation at higher voltages so that the higher efficiency can be realized.

EXPERIMENTAL METHOD

The fission cross sections were measured by the time-of-flight technique using the 30-MeV electron linear accelerator at Lawrence Radiation Laboratory as the pulsed neutron source. The electron target was a 5-cm-diam by 5-cm-thick slug of depleted uranium surrounded by a 3-cm layer of transformer oil. The neutron flight path for these experiments was 5.50 m. The drift tube made an angle of 10° with the electron beam direction. The neutron beam at the detector was 7.5 cm in diameter with a penumbra about 1 cm wide. To reduce the background from extraneous neutrons, the detector was surrounded on all sides, except for beam access holes at the front and back of the detector, by a shield consisting of 30 cm of paraffin that was lined on the inside with 0.08 cm of cadmium. The fission chamber signals from the detector were attenuated, passed through a discriminator to eliminate cable "pick-up" or other noise, and recorded on a 1024-channel time analyzer.

TABLE II. Experimental conditions for the fission spectrum measurements.

	Energy interval	Filters	Machine rep. rate (pulses/sec)	Machine pulse length (μsec)	Time anal. chan. width (μsec)
Series *A*	1–160 eV	Cd, Rh, Co	200	1	0.5
Series B	0.032–3 eV	None	200	2	2
Series C	0.4–16 eV	None	200	2	0.5

The first measurements of the neutron flux were made with a BF_3 tube filled to a pressure of 15-cm Hg and placed inside the spark chamber immediately behind the Am^{241} fission foils. At this position the neutron detectors saw the same primary beam and background as the fission foils. However, severe saturation difficulties were encountered in the BF_3 tube and its associated circuitry due to the intense gamma flash produced by the electron beam. Even at considerably reduced beam intensity it was very difficult to determine with certainty the time at which all components of the system had recovered enough for accurate flux measurements.

This difficulty was resolved by substituting for the BF_3 tube a small spark chamber (with fundamentally the same design as the fission chamber) that was provided with a Li^6 radiator. This detector was completely independent of the Am^{241} fission fragment detector and was small enough to fit inside it in the same position as the BF_3 tube. The Li^6 radiator consisted of a 0.15-mg/cm^2-thick layer of Li^6 oxide on a 0.045-cm-thick aluminum foil. The detector was filled with CO_2 at a pressure of 85 cm of Hg to enhance the efficiency for detection of alpha particles or tritons. Unfortunately, the detector was developed in the course of these measurements after it became apparent that the BF_3 tube would not be satisfactory. It was too late, therefore, to measure the neutron flux simultaneously with

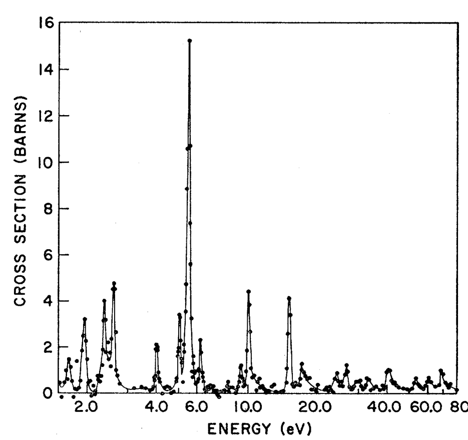

FIG. 3. The fission cross section of Am^{241} in the energy interval from 1.5 to 80 eV. The solid line through the points is included to guide the eye.

the fission spectra, although measurements were made under the same machine conditions.

The fission cross-section measurements which covered the energy range from 0.032 to 80 eV are presented in Figs. 2 and 3. Measurements were made in three energy intervals: (1) from 1 to 160 eV, (2) from 0.032 to 3 eV, and (3) an overlapping measurement joining the high- and low-energy measurements. These measurements will be hereafter referred to as Series A, Series B, and Series C, respectively. The experimental conditions under which these three series of measurements were made are given in Table II.

For the Series-A measurements, filters of Cd, Rh, and Co were located midway between the detector and the neutron source. These filters were necessary to reduce and measure backgrounds. The 0.080-cm-thick Cd filter, which stopped all neutrons having energy less that 0.25 eV, eliminated overlap of the low-energy neutrons from one burst into the next. The thickness of the Rh and Co filters was enough to absorb or scatter all neutrons near the resonance at 1.26 eV in the rhodium and at 132 eV in the cobalt. Both dips in the fission spectrum indicated the same background correction, which was 4.5 events per channel. Consequently, the background correction was assumed to be the same for all channels in the analyzer spectrum. The neutron spectrum obtained with the spark chamber was background corrected in a similar manner. The $1/\sqrt{E}$ dependence was also removed and the resulting neutron spectrum was divided into the fission spectrum to give an unnormalized fission cross section in the higher energy interval.

For the Series-B measurements, all filters were removed from the beam. After completing both neutron and fission spectrum measurements under the beam pulse and channel width conditions specified in Series B of Table II, the neutron spectrum was remeasured at a pulse rate of 100 pulses/sec and with a channel width of 8 μsec. At this lower repetition rate no overlap problem existed since the energy of all overlap neutrons was less than 0.0016 eV and the flux below this energy is extremely small. The wider channel width allowed measurements to be extended as low as 0.0023 eV. Using this neutron spectrum along with the thermal value for the fission cross section as measured by Hulet *et al.*[6] and the measurements of Leonard,[2] which show that the Am^{241} is essentially $1/v$ in the overlap region, it was possible to correct the fission spectrum for overlap neutrons.

The time-independent background arising from spontaneous breakdown and from alpha particle pile-up in the fission chamber was monitored during the Series-B fission measurement by recording the pulses in the interval between 4 and 5 msec after the machine burst. During this time interval virtually no fission is induced by the neutrons. It was therefore possible to obtain a constant background to be subtracted from each channel in the Series-B measurements. This background was consistent with that measured with the machine off.

The accuracy of the background treatment outlined above was checked near 2 eV by comparing the peak-to-valley ratio at the 1.93-, 2.36-, and 2.60-eV resonances in the Series-B measurements with those in the Series-A measurements. The accuracy was checked in the region below 0.1 eV by comparing the background-corrected cross section to a $1/v$ cross section expected there on the basis of Leonard's measurements. These comparisons indicated that the background treatment of the Series-A measurements was satisfactory at either end of the spectrum and therefore gave confidence in the background corrections applied in the energy range between 0.1 and 2 eV.

To obtain an absolute cross-section scale for these data, the Series-B measurements were extrapolated to 0.025 eV and normalized at that energy to the thermal value of 3.13 ± 0.15 b.[6] To normalize the Series-A measurement to the Series-B data, another measurement was made which overlapped the large resonances at 1.27 and 5.48 eV. The operating conditions for this measurement are given as Series C in Table II. This overlap data was normalized to the Series-B data by comparison of areas under the 1.27-eV resonance. The area of the 5.48-eV resonance in the overlap measurement could then be determined in units of barn-eV. The Series-A data were normalized by comparing the area of the 5.48-eV resonance to that of the normalized overlap data. This procedure was checked by comparing the combined area under the 2.36- and 2.60-eV resonances as determined in both Series-A and B measurements. The two areas differed only by 5%.

RESULTS

All of the 11 resonances observed below 6.5 eV in the total cross-section measurement[7] of Am^{241} were observed in these measurements, except for the small resonance at 4.40 eV, which is only weakly indicated in the fission data. Another small resonance at 1.68 eV, which appears to be weakly indicated in the total cross section, was observed in the fission measurements. Above this energy the experiment was not sensitive enough to observe more than a few resonances. Inadequate resolution and statistical uncertainties were the main limitations. The standard deviation of the points in the valleys above 6 eV is about 50%.

The resonance parameters for the three lowest energy resonances have been determined by shape-fitting these resonances with the sum of three Breit-Wigner single-level formulas, taking into consideration the resolution and the Doppler effect. The fit is shown

[6] E. K. Hulet, H. R. Bowman, M. C. Michel, and R. W. Hoff, Phys. Rev. **102**, 1621 (1956).

[7] J. A. Harvey, R. C. Block, and G. G. Slaughter, Bull. Am. Phys. Soc. 4, 34 (1959).

TABLE III. Am^{241} resonance parameters.

E_n (eV)	$g\Gamma_n$[a] (meV)	Γ_f/Γ[b] $\times 10^{-2}$	Γ_f/Γ[c] $\times 10^{-2}$	Γ[d] (meV)	Γ_f[d] (meV)
−0.66[e]					
0.310	0.030 ±0.003			48 ± 5	0.31 ±0.07
0.575	0.037 ±0.004			60 ±10	0.23 ±0.06
1.270	0.195 ±0.010			50 ± 5	0.35 ±0.06
1.270	0.195 ±0.010	0.61 ±0.06			
1.68[f]					
1.93	0.063 ±0.003	0.20 ±0.04	0.14		
2.36	0.040 ±0.006	0.37 ±0.10	0.37		
2.60	0.100 ±0.010	0.27 ±0.04	0.25		
4.00	0.130 ±0.013	0.035 ±0.009	0.022		
4.40	0.013 ±0.004	<0.2			
5.05	0.171 ±0.017	0.078 ±0.019	0.065		
5.48	0.524 ±0.014	0.96 ±0.010	0.99		
6.20	0.065 ±0.020	0.083 ±0.040	0.062		
9.30	0.201 ±0.025	0.12 ±0.034			
10.05	0.168 ±0.025	2.40 ±0.34			
15.04	1.20 ±0.25	0.73 ±0.15			

[a] These parameters are taken from Ref. 7.
[b] These parameters were derived by area analysis. The errors are computed from uncertainties in both $g\Gamma_n$ and area measurement.
[c] These parameters were obtained by area analysis using an IBM 7094 computer.
[d] These parameters were obtained from the shape fit.
[e] A value for $g\Gamma_n^0\Gamma_f$ of 6.7×10^{-8} eV^2 was determined for this resonance from the shape fit.
[f] This resonance only weakly indicated in the total cross section; $\sigma_0\Gamma_f = 0.05$ b-eV.

by the solid line through the data of Fig. 2. The parameters for these resonances which were obtained from the fit and the total cross-section values of $g\Gamma_n$ are given in columns 5 and 6 of Table III. A negative energy level at −0.66 eV was included to obtain a fit to the data in the region below 0.1 eV. A value for $g\Gamma_n^0\Gamma_f$ of 6.7×10^{-8} eV^2 was obtained for this resonance. The errors on Γ are estimated to be limits beyond which the fit to the data would be noticeably poorer. The errors on Γ_f are computed by compounding the errors in $g\Gamma_n$ and Γ.

As evidenced by this fit, interference effects in the fission cross section of Am^{241} are small. Differences between the experimental curve and the theoretical fit might be attributed to interference effects, but perhaps equally well to experimental uncertainties.

These data and Leonard's agree quite well on the whole. The most noticeable difference occurs in the neighborhood of the 0.575-eV resonance, which Leonard found to be narrower with a somewhat larger peak cross section. The values for the fission width deduced by Leonard were computed using early values of $g\Gamma_n$ obtained from total cross sections. Satisfactory agreement with the parameters reported here is obtained using the more recent values.[7]

The line through the data of Fig. 3 serves only to guide the eye. The resonance parameters at higher energies were obtained from area analysis of the data both by hand and by computer. A total width of $\Gamma = 50$ mV was used for wing corrections to the area analysis carried out by hand. This value was based on the results obtained for the first three resonances. The values of $g\Gamma_n\Gamma_f/\Gamma$ determined from the analysis were divided by $g\Gamma_n$ to obtain the values for Γ_f/Γ of column three of Table III. The errors were computed by compounding the uncertainties in definition of area and in the values for $g\Gamma_n$.

A computer program developed by Atta and Harvey[8] for area analysis of total cross-section data was adapted for area analysis of fission data and also applied to the data between 1.5 and 8 eV. For an assumed value of Γ which was taken to be the same for all resonances, the program computed a value of $g\Gamma_n^0\Gamma_f/\Gamma$ for each resonance in the energy interval under study. Using these parameters, the resolution and Doppler-broadened cross section was then computed and compared to the experimental data. The best fits to the cross section were obtained using a value of $\Gamma = 50$ when a temperature of 300°K was assumed for the Doppler-broadening calculation. The values for Γ_f/Γ obtained from this computation are listed in column four of Table III. A value for $\sigma_0\Gamma_f$ of 0.05 b-eV was obtained for the very weak resonance at 1.68 eV.

INTERPRETATION

In this experiment it was possible to detect all except one of the 11 resonances below 6.5 eV that were observed in the total cross-section measurement. The average value of the fission width obtained from these resonances, assuming $\Gamma = 50$ mV, is 0.18 ± 0.06 mV. Leonard[2] has fitted Eq. (1) to the fast-neutron fission threshold[9] in Am^{241} and determined the parameters of the equation to be $\hbar\omega = 0.99$ MeV and $E_t = 0.93$ MeV. Using these parameters and the spacing obtained from total cross sections, the equation predicts that the average fission width at zero neutron energy should be 0.23 mV in good agreement with the value found experimentally.

This good agreement is somewhat surprising since Eq. (1) describes the energy dependence of the fission width for only a single fission channel.[1] It is not certain that more than one channel contributes to the fast-neutron fission threshold. However, it is very likely that at least two channels are open to nearly the same degree at low energies. The addition of an S-wave neutron to the target nucleus Am^{241} with spin and parity $I^\pi = \frac{5}{2}^-$ may excite either of two spin states in Am^{242} with $J^\pi = 2^-$ and 3^-. According to the $(2J+1)$ rule,[10] these spin states should be almost equally represented in the sample of resonances below 6.2 eV so that at least two fission channels should be present, corresponding to the two spin states. The fission channels belonging to the two spin states apparently are open to about the same degree since as many resonances were observed below 6.5 eV as were seen in the total cross-section measurements. Therefore, the fission thresholds for the two spin states probably lie rather closely in energy. The parameters of Eq. (1), derived from the

[8] S. E. Atta and J. A. Harvey, Oak Ridge National Laboratory Report No. ORNL-3205 (unpublished).

[9] R. A. Nobles, R. L. Henkel, and R. Smith, Los Alamos, Brookhaven National Laboratory Report No. 325, 1958, 2nd ed. (unpublished).

[10] C. Bloch, Phys. Rev. **93**, 1094 (1954).

fit to the fast fission data, would then be average values for the two spin states.

The foregoing arguments imply that there is at least one partially open fission channel associated with each spin state. An analysis of the fission width distribution has been developed by Wilets[11] that allows one to estimate the number of channels participating in the fission, even though all channels may not be open to the same degree. He defines an effective number of channels $\nu_{\rm eff}$ as the ratio

$$\nu_{\rm eff}=\frac{(\Sigma\nu_\alpha)^2}{\Sigma\nu_\alpha{}^2}=\frac{\langle 2\Gamma_f\rangle}{\langle\Gamma_f{}^2\rangle-\langle\Gamma_f\rangle^2}, \qquad (2)$$

where $\langle\Gamma_f\rangle$ is the average fission width and ν_α can be interpreted as the degree of "openness" of channel α. When applied to the levels below 6.5 eV, this equation gives $\nu_{\rm eff}=2.9\pm0.6$ channels, indicating that as few as two and probably no more than four channels are important in the fission of Am^{241}.

Bohr[12] has proposed a model for fission which satisfactorily accounts for the fission event as a few-channel process. He assumes that the major portion of the energy of the fissioning nucleus near the saddle point is potential energy of deformation. Only a small amount of energy is available for intrinsic excitations within the nucleus. The spectrum of states of the nucleus is therefore expected to be quite similar to the spectrum near the ground state of the highly deformed nuclei, i.e., consisting of rotational bands built upon intrinsic and vibrational states. Consequently, only a relatively few states should be available to the fissioning nucleus.

The spectrum of levels near the ground state of the odd-odd compound nucleus Am^{242} is therefore of interest. Little information is available on the odd-odd nuclei in general. However, in most cases the configurations of two of the lowest lying intrinsic states can be predicted on the basis of Nilsson orbitals.[13] The most likely odd neutron orbital has $\Omega^\pi=\frac{5}{2}+$ where Ω is the projection of the particle angular momentum on the cylindrical symmetry axis of the nucleus and π is the parity. The most likely odd-proton orbital has $\Omega^\pi=\frac{5}{2}-$. The quantum number K, which is the projection of the total angular momentum on the nuclear symmetry axis, takes on the values 0^- and 5^-. Systems of rotational levels may be built on these intrinsic excitations.

The level structure near the ground state of Am^{242} is consistent with that expected on the basis of Nilsson orbitals. The ground-state spin of Am^{242} is known[13] to be 1^-. The only excited state known[13] is a 5^- level located 48.5 keV above the ground state. The 5^- level is thought to be the base level of a $K^\pi=5^-$ rotational band. The 1^- ground state is thought to be the first rotational member of the $K^\pi=0^-$ rotational band, which is depressed below the 0^- level due to special considerations peculiar to odd-odd nuclei.[13] Therefore, both the 2^- and 3^- members of the $K^\pi=0^-$ rotational band may be excited by the absorption of s-wave neutrons in Am^{241}. Since these states are members of the same rotational band, they lie quite close in energy so that the thresholds for the two channels should also lie close in energy and, for neutron-induced fission, both channels should be open very nearly to the same degree. Vibrational states or other intrinsic excitations upon which other rotational bands might be based are expected to be found several hundred keV above the 0^- rotational band. Therefore, on the basis of the Bohr model, it is not expected that channels based on levels that are members of these high-lying bands will be open to the same degree as those of the $K=0^-$ band.

In summary, it appears that subthreshold fission of Am^{241} is characterized by fission through only a few channels with at least one fission channel belonging to each spin state accessible by slow neutron capture. The channels for both spin states are open to nearly the same degree, having nearly the same threshold energies, and therefore cannot be distinguished from one another in the fast-neutron fission-threshold measurements. These views are consistent with the Bohr model for fission, assuming that the low-lying levels in Am^{242} have been properly interpreted.

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[11] L. Wilets, Phys. Rev. Letters **9**, 430 (1962).
[12] A. Bohr, in *Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955* (United Nations, New York, 1956), Vol. 2, p. 151.
[13] F. Asaro, I. Perlman, J. O. Rasmussen, and S. G. Thompson, Phys. Rev. **120**, 934 (1960).