SOVIET PHYSICS JETP VOLUME 15, NUMBER 1 JULY, 1962

NUCLEAR SHELLS AND PROMPT FISSION NEUTRONS

M. V. BLINOV and V. P. ÉĬSMONT

Submitted to JETP editor June 21, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **42**, 180-182 (January, 1962)

An explanation of some recently-discovered features of prompt neutron emission is proposed. The explanation is based on taking into account the effect of closed nuclear shells on the fragment shape before fission.

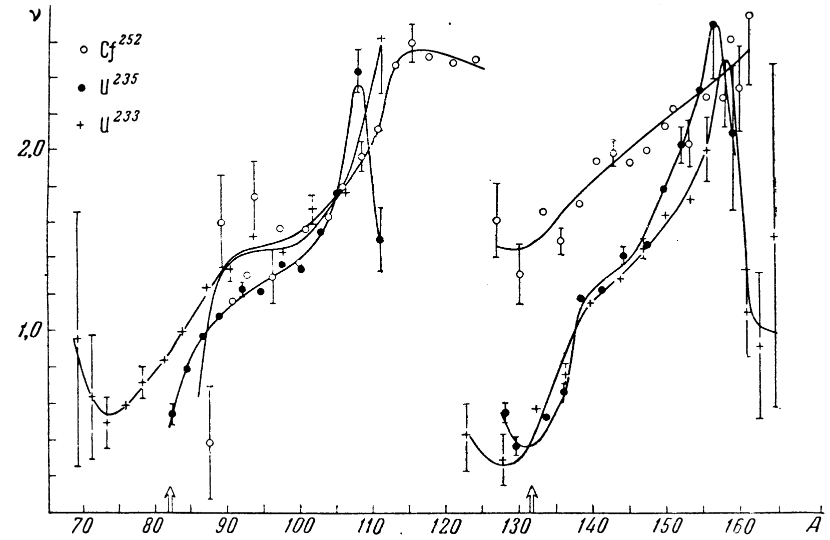
THE study of the relationship between the number of prompt neutrons ν and the mass A of the fragment has led to remarkable results. It has been established[1] that in the thermal neutron fission of U^{233} the greatest number of neutrons is emitted by the heavy fragments of the heavy group and by the heavy fragments of the light group. The most remarkable was that fragments of a comparatively equal mass ($A_h/A_l \approx 1.1$) emit noticeably different numbers of neutrons. Whetstone,[2] employing Vladimirskii's idea,[3] has offered as an explanation a simple model, whereby the greatest difference in the number of emitted prompt neutrons is expected in strictly symmetrical fission, when the light fragment receives the maximum fraction of deformation energy, and in strongly asymmetrical fission, when almost all the deformation energy is received by the heavy fragment.

Experimental data however, obtained in studies of the function $\nu(A)$ for "thermal" fission of U^{235}[4] and spontaneous fission of Cf^{252},[2] do not meet with these expectations. Results of the last two and of the first mentioned papers are combined in the graph.

It can be seen from the figure that in the fission of all elements (U^{233}, U^{235}, Cf^{252}) the smallest number of neutrons is emitted from the heavy fragments with $A_h \approx 125-130$ and from the light fragments with mass $A_l \approx 75-85$, while the largest number comes from the complementary fragments. However, in the regions of the almost symmetrical,* asymmetrical (close to the most probable), and strongly asymmetrical fission ($A_h \approx 160$, $A_l \approx 70-75$) a tendency is observed toward equalization of ν for the light and heavy fragments. These results can be understood if it is assumed that the effect of the closed shells is manifest on the form which the fragments have before the instant of the final fission. Indication of such an influence by the shells has been obtained in [5], in an investigation of the dependence of the kinetic energy of the fragments on their mass; it has also been noted there that the effect can have a bearing on the emission of prompt neutrons. It can be expected that the heavy fragment, with close to 50 protons and close to 82 neutrons, will be almost spherical before fission and all the deformation energy is concentrated in the light fragment. Fragments with mass $A_h \approx 132$ therefore will emit few neutrons, and the complementary fragments many neutrons. This conclusion, as can be seen in the figure, is verified by experiment. It can be therefore assumed that the light fragment with 50 neutrons and therefore with a mass close to 80 will also be deformed slightly, while the complementary heavy fragment will be strongly deformed and will emit a large number of neutrons (see the figure). In the regions of the almost symmetrical, asymmetrical (close to the most probable), and strongly asymmetrical fissions, in which the shell effects are not pronounced, the light and heavy fragments can emit an almost equal number of neutrons.

It is interesting to note, that the difference in the number of neutrons emitted from the magic heavy and the complementary light fragments is considerably smaller for Cf^{252} than for U^{233} and U^{235}. This can be easily understood by recognizing that in the case of Cf^{252} the fragment complementary to the magic one is close to it in mass and consequently in deformability. This explains why the ratio of the mean number of neutrons emitted from the light fragment to the mean number of neutrons from the heavy fragment is smaller for Cf^{252} (1.02) than for U^{233} and U^{235} (1.2 — 1.3). In the fission of elements heavier than Cf^{252} light fragments will probably emit as many neutrons as the heavy fragments or even fewer (when the magic nuclei with $A \approx 132$ are among the light fragments).

*The tendency toward equalization of ν in the symmetrical region can not be fully attributed to the dispersion in the determination of the masses at dispersion values obtaining in the measurements described in[1,2,4].



Probability of neutron emission as a function of the mass numbers of the fragments. The arrows indicate the mass numbers corresponding to the magic nuclei. All data are normalized to the absolute value of the mean ν. Corrections for the angular distribution of neutrons are introduced both for U^{233} [1] and U^{235} [4].

The indicated behavior of neutron emission allows us to advance certain ideas concerning the "fine structure" of the fragment mass distribution, namely an increase in the yield of fragments with A ≈ 134 and of the complementary light fragments. An increased yield of such fragments can be expected if it is kept in mind that in the region where the shells appear (A ≈ 132) and in the complementary region of light fragments, the greatest variation* of ν with A (see the figure) takes place and consequently also the most noticeable increase in fragment yield owing to emission of neutrons from the neighboring heavier fragments. And although from this point of view the "fine structure" is due to a process that occurs after fission (emission of neutrons from the fissioned fragments), it can be easily seen that it will also be manifest in the complementary fragment, since the distribution of excitation energy (and consequently also of ν) is determined by the effect of the shells on the form of the fragments prior to fission.

The authors are thankful to B. M. Shiryaev and I. T. Krisyuk for a useful discussion of the work.

*Because of the measurement dispersion, the true function ν(A) may be significantly more abrupt than the one observed experimentally.

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Translated by A. V. Ilyinsky
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