Effects of polarization of the target nuclei in fission of ^{235}U by neutrons

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The (n,f) reaction has been studied in polarized ^{235}U nuclei over the neutron energy range 10–200 keV. The effects of the polarization in the total fission cross section and in the angular distribution of fragments were measured. The results are interpreted on the basis of a partial conservation of the quantum number K in the reaction in which the compound nucleus is formed and in the states that form.

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It has been pointed out in several places (see Ref. 1, for example) that contradictions arise in attempts to use a common structure of fission channels to describe the cross sections and angular distributions of the fragments of the same compound nuclei formed in reactions of two types: in spinless target nuclei in (γ,f) and (t,pf) reactions and in nuclei with nonzero spin in (n,f) and (d,pf) reactions. One of the physical reactions for this discrepancy may be an approximate conservation of the quantum number K (the projection of the total angular momentum J on the symmetry axis of the nucleus) during formation of the compound nucleus and in its excited states near the neutron binding energy. During the absorption of s-wave neutrons by a ^{235}U nucleus, the angular momenta combine in the proper frame of reference in such a way that 3^- states form with only $K=J=3$, while 4^- states form with only $K=4$ or 3. A simple kinematic calculation shows that values of K approximately equal to J continue to be predominant in the absorption of p-wave and d-wave neutrons. Accordingly, values $K\sim J$ are emphasized and values $K\sim 0$ are forbidden by the process by which the compound nucleus forms, while the structure of the fission channels leads to the opposite results. The product of these two distributions, which are asymmetric in different ways, should have a maximum at $K=1$-2. These qualitative arguments are in agreement with Fig. 1, which is plotted from measurements of the angular anisotropy of the (n,f) reaction in individual resonances in a polarized ^{235}U target.[2]

In the present experiments we studied the (n,f) reaction in polarized ^{235}U nuclei at higher neutron energies, at which the s-wave and p-wave neutrons dominate the reaction. In contrast with the resonance energy region, the observable quantities at these higher energies are averaged over compound-nucleus levels which have different properties. The involvement of p-wave neutrons in the reaction raises the possibility of also observing an effect of the polarization of the target nuclei on the total fission cross section. The neutrons for the fission reaction were produced in the $^7Li(p,n)^7Be$ reaction in the beam from a KG-2.5 tandem accelerator, which was incident on a target of metallic lithium on a copper substrate. The ^{235}U nuclei were

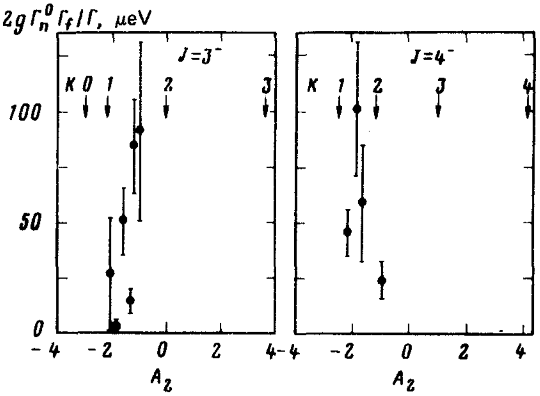

FIG. 1. Distribution of $2g\Gamma_n\Gamma_f/\Gamma$ in A_2, the coefficient in the angular distribution of the fragments in the fission of polarized ^{235}U nuclei by resonant neutrons (according to the results of Ref. 2). The arrows show the values of A_2 corresponding to definite values of K.

polarized by a method similar to that used in Refs. 2 and 3. The isotopically pure ^{235}U sample (99.99%), with a thickness of 0.5 mg/cm^2, was cooled in an adiabatic-demagnetization crystat to 0.2 K. The C axis of the single-crystal sample was oriented along the neutron beam. The fragments were detected by silicon surface-barrier detectors held at 4.2 K (Ref. 4).

Two detectors were used to measure the 0-90° angular anisotropy, while a third monitored the neutron flux density through the sample. For the use of this third detector, a film of unpolarized ^{235}U was deposited on the rear side of the copper substrate of the target. It was thus possible to measure two effects of the nu-

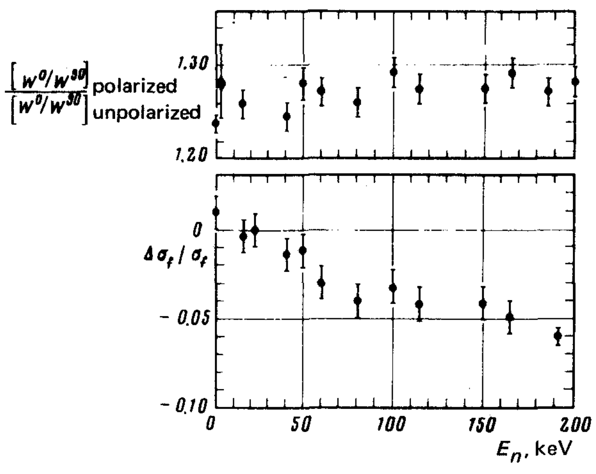

FIG. 2. Top: Effect of the polarization of the ^{235}U target nuclei in the angular distribution of the fragments of the fission caused by neutrons. Bottom: The effect in the fission cross section. ♦–Results of Ref. 2, corrected to the conditions of the present experiments; •–present experiments. The points on the ordinate axis correspond to measurements with thermal neutrons.

clear polarization—in the total fission cross section and in the angular distribution—in a single experiment.

Figure 2 shows the experimental results and the statistical errors. The systematic errors result from corrections for the experimental geometry and are ±0.005 for the effect in the cross section and ±0.014 for the angular anisotropy. The rms energy spread of the neutrons was no greater than 20 keV.

The polarization effect in the cross section can be expressed in a simple way in terms of the average widths and the kinematic coefficients for the *p*-wave neutrons, which have their greatest effect at $E_n \sim 100$ keV. The effect in the cross section indicates that the J distribution of the fission probability in the compound nucleus is very nonuniform. It must be assumed on the basis of the kinematics of this reaction that the 3^+ and 4^+ states definitely make a predominant contribution to the cross section for fission by *p*-wave neutrons, while the 2^+ and 5^+ states, whose combined statistical weight is half that of the two former states, is suppressed further by a factor of $\Gamma_n\Gamma_f/\Gamma$. We may ignore the contribution of these states for a qualitative comparison of the experimental results with theoretical predictions. If we make the further assumption that the only possible values of K are 1 and 2, on the basis of the arguments above, we can offer a joint explanation for the observations both in the resonance energy region and at neutron energies at which the *s*-wave and *p*-wave neutrons make comparable contributions.

In conclusion we wish to emphasize again that calculations based on the conventional assumptions regarding the reaction kinematics and which use the familiar structure of the fission channels will unavoidably lead to sharp discrepancies with experiment (see also Ref. 5).

1. Yu. B. Ostapenko and G. N. Smirenkin, Materialy V Vsesoyuznoi konferentsii po neĭtronnoĭ fizike (Proceedings of the Fifth All-Union Conference on Neutron Physics), Kiev, 1980, Part 3, p. 73.
2. N. J. Pattenden and H. Postma, Nucl. Phys. **A167**, 225 (1971).
3. J. W. T. Dabbs *et al.*, Proceedings of the Symposium on the Physics and Chemistry and Fission, Salzburg, 1965, Vol. 1, 37.
4. N. N. Gonin *et al.*, Cryogenics **18**, 57 (1978).
5. N. N. Gonin *et al.*, Yad. Fiz. **22**, 692 (1975) [Sov. J. Nucl. Phys. **22**, 358 (1975)].

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