THE BLOCKING EFFECT IN URANIUM FISSION

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Blocking in the directions of the crystallographic axes and planes was observed in the angular distribution of U^{238} fission fragments produced by bombarding a UO_2 single crystal with 25-MeV α-particles. Blocking patterns associated with the entire set of crystal axes and planes (the so-called "fragmentograms") were obtained. The possibility of using this effect to study the time parameters of fission is discussed. The upper limit of the lifetime for fission is $\sim 10^{-17}$ sec.

1. The blocking effect that is observed when fast charged particles interact with single crystals[1,2] is being studied intensively at the present time, and especially in connection with the elastic scattering of charged particles.[3-5] Observations of blocking have also been reported in the (d, p) reaction,[3] and in the emission of α particles,[2] positrons, and electrons[6] by radioactive nuclei embedded in single crystals. Two possible ways of utilizing the effect have been mentioned: for the structural analysis of solids, and for measuring the ultrashort durations of nuclear reactions.

Having in mind the second use, we attempted to observe the blocking effect in the fission of uranium atoms which are constituents of a single crystal. Extremely little information is available regarding the lifetime for fission of nuclei, i.e., the interval from the moment when a fission-inducing particle enters a nucleus to the moment when the nucleus splits into fragments. Only in the case of slow-neutron fission, when individual levels of the compound nucleus are excited near the fission barrier, has the absolute value of the fission width been measured so that the lifetime for fission can be determined. For resonances in the indicated neutron energy region the fission widths are of the order 0.1 eV, which corresponds to 10^{-14}-sec duration of the fission process.[7] At higher excitation energies, particularly in fission induced by charged particles, the widths of levels become comparable with their separations and it becomes impossible to measure the fission widths directly. It appears that in this case the blocking effect could be used to obtain information regarding the lifetime for fission.

The fact that blocking is observed in the angular distribution of fragments indicates that the momentum of the bombarding particle causes the compound nucleus, during its lifetime, to be displaced from its site in the crystalline lattice by a distance not greatly exceeding the screening parameter. In the absence of blocking the displacement markedly exceeds the screening parameter.

2. Our experiment was performed at the cyclotron of the Institute of Nuclear Physics (Moscow State University). A 25-MeV α particle beam of 0.5-mm diameter bombarded a UO_2 single crystal of natural isotopic composition. The uranium fission fragments were registered by means of a technique that is highly selective for fragments against a high α-particle background; a glass detector was used.[8] Control measurements, when we placed in front of the glass an absorber that was twice as thick as the fragment range but only one-tenth as thick as the range of scattered α particles, confirmed the total insensitivity of the detector to α particles. The experimental geometry is shown in Fig. 1. Preliminary orientation of the target crystal was performed on the cascade accelerator of the Institute of Nuclear Physics by observing the blocking effect in the elastic scattering of 500-keV protons.

After the target had been bombarded during two hours with α particles forming a 3×10^{-9}-A mean current and the glass detecting plates had been processed chemically, a system of attenuations (represented by transparent spots and lines) was clearly visible against a mat background. Figure 2a is a photograph of one plate, obtained with side illumination. Figure 2b shows, for comparison, the blocking pattern obtained when 500-keV protons were scattered elastically by the same crystal; this is a so-called "protonogram" and Fig. 2a can be called a "fragmentogram" by analogy. Figure 2c is a geometric pattern representing intersections of low-index crystallographic axes and planes with the plane of the detector. The quantitative treatment of the results involved microscopic counting of fragment tracks in the glass. Figure 3 shows diametral cross sections of the ⟨110⟩ and ⟨211⟩ axial dips (attenuations) at 150° to the α-particle beam and of the ⟨110⟩ axial dip at 90°.

3. Our data enable us to estimate the upper limit for the lifetime of the fissioning nucleus. A dip was observed at 90° to the α-particle beam, when the displacement of the nucleus induced by the α-particle momentum was maximal in a direction perpendicular to the crystallographic axis. An indication is thus obtained that this displacement does not greatly exceed the screening parameter of the nuclei involved in blocking. The screening parameter for uranium is $\sim 10^{-9}$ cm and the velocity that an α particle imparts to a nucleus is $\sim 6 \times 10^{7}$ cm/sec. From this we estimate the lifetime for fission, $\tau \sim 10^{-17}$ sec.

It is noteworthy that the dips (attenuations) for fragments are relatively shallow, possibly because of imperfect crystal structure. Another cause could be a large displacement of the fissioning nucleus, so that the dips begin to disappear, and our upper limit of the lifetime for fission would be close to the actual value. The

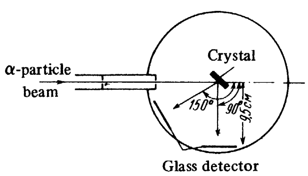

FIG. 1. Scheme of the experiment.

lifetime of the fissioning nucleus could evidently be determined through a detailed analysis of the forms exhibited by the dips in the region where the axial and linear attenuations coincide, because there are indications that this region is most sensitive to the displacement of a nucleus from its lattice site.[9] It should be noted that a close value of the limit of τ was obtained in[10] (which was published while we were performing our work), where a $\langle 110 \rangle$ dip was observed when uranium fission was induced by 12-MeV protons.

4. The blocking effect in nuclear fission could also be of interest for the investigation of other problems. An example is the problem of the charge possessed by fragments immediately after the fission event. The parameters of the dips, particularly their width, depend to a considerable degree on the charges of the fragments at the moment when they interact with the nearest neighbors of the fissioning nucleus. This charge of a fragment could evidently differ from the equilibrium charge that it acquires in the course of its collisions with atoms of the medium during its subsequent motion.

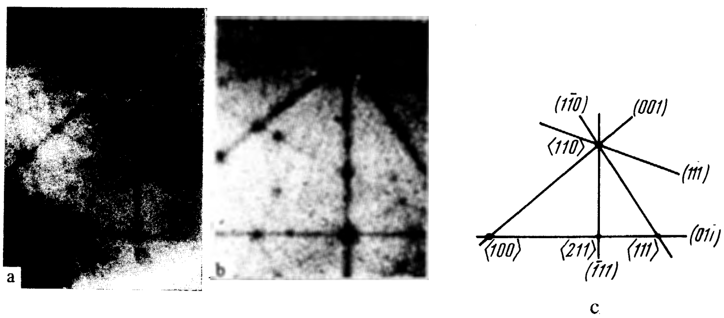

FIG. 2. (a) "Fragmentogram", (b) "protonogram", and (c) geometric scheme of the blocking pattern representing the intersection of the principal crystallographic axes and planes with the plane of the detector, for a UO_2 single crystal.

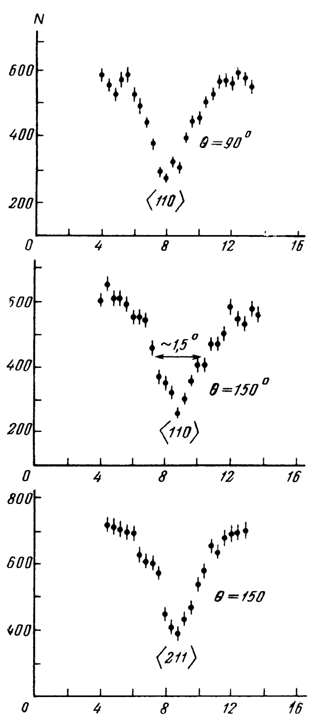

FIG. 3. Angular distribution of U^{238} fission fragments near the ⟨110⟩ and ⟨211⟩ crystallographic axes of a UO_2 single crystal at 90° and 150° to the α-particle beam. N is the number of fragments in a 0.5 × 0.5-mm area; l is the coordinate along the direction in which the fragmentograms is scanned.

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