

# On the Measurement of Fission Angular Distribution in Solid State Detectors

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It has been discovered by SILK, BARNES, and HAWWELL<sup>1</sup>, that the radiation damage produced by the passage of charged particles in mica may be rendered visible in an electronic microscope. Since then it has been shown, that several cristals, glasses and plastic materials are likewise suited as track-forming detectors. The possibility of developping the tracks to sizes, where they may be scanned under an optical microscope, has further stimulated the application of these detectors<sup>2</sup>. The existence of a critical ionization, below which no tracks are seen, makes feasible the investigation of nuclear reactions where heavy ions are to be discriminated against a high background of light charged and neutral particles, as e. g. in nuclear fission induced by neutrons,  $\gamma$ 's, protons etc. With this technique fission cross sections, angular, mass, and kinetic energy distributions may be measured. It is the purpose of this note, to describe a method adapted to solid state detectors for taking angular distributions of fission fragments with an optical microscope.

To take angular distributions with mica or plastic detectors, the detector — normally a thin sheet or foil — is coated with a layer of the target material. The alignment of the detector foil should preferentially be parallel to the projectile beam inducing fission for the following reasons. In the absence of polarization effects the expression for the angular distribution  $W(\theta, \varphi) d\Omega$  reduces to  $W(\theta) d\Omega$ . In the above setup of beam and detector, the whole distribution  $W(\theta) d\Omega$  is seen in principle for fragments forming grazing angles with the detector surface. In practice, however, only tracks with a minimum dip angle of, say  $5^\circ$ , relative to the detector plane are registered with 100% efficiency. On the other hand, large dip angles are difficult to measure under the microscope. One has therefore to compromise, and choose fragment tracks lying in a dip angle interval between  $5^\circ$  and  $20^\circ$  for example. The quantities determined then are the angle  $\alpha$  of the track projected on the microscope plane relative to the incoming beam direction and the dip angle  $\delta$ . The transformation from one set of parameters  $(\theta, \varphi)$  to the other  $(\alpha, \delta)$  is straight-forward.

From Fig. 1 the relations

$$\cos \Theta = \cos \delta \cos \alpha \quad (1)$$

and

$$\sin \delta = \sin \Theta \sin \varphi \quad (2)$$

<sup>1</sup> E. SILK, R. BARNES, and A. HARWELL, *Phil. Mag.* **4**, 970 [1959].

<sup>2</sup> R. L. FLEISCHER, P. B. PRICE, and R. M. WALKER, *Ann. Rev. Nucl. Science* **15**, 1 [1965].

are read. Calculating the JACOBIAN yields

$$\begin{aligned} W(\Theta) \sin \Theta \, d\varphi &= W(\arccos(\cos \alpha \cos \delta)) \cos \delta \, d\alpha \, d\delta \\ &= \widetilde{W}(\alpha, \delta) \cos \delta \, d\alpha \, d\delta. \end{aligned} \quad (3)$$

In a simple example  $W(\Theta) = a + b \cos^2 \Theta$  one obtains

$$\tilde{W}(\alpha, \delta) = a + b \cos^2 \delta \cos^2 \alpha.$$

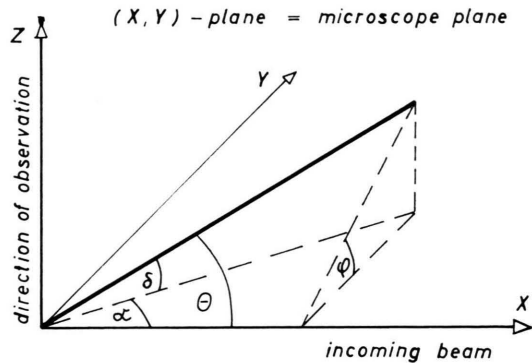


Fig. 1. Sketch showing a fragment track and the angles defined in the text.

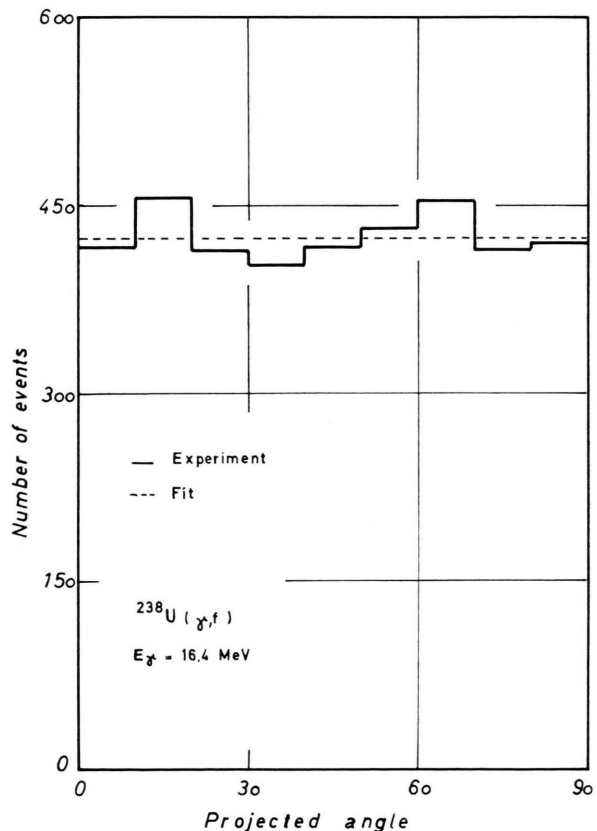


Fig. 2. Distribution of the projected angle  $\alpha$  for the reaction  $^{238}\text{U}(\gamma, f)$ .

Now if a small  $\delta$ -interval is taken and kept fixed, as indicated above,  $\cos \delta$  and  $\cos^2 \delta$  may be replaced by their mean. A least square fit to the measured  $\alpha$ -distribution yields in the example given the coefficients  $A$  and  $B$  of

$$\tilde{W}(\alpha) = A + B \cos^2 \alpha,$$

with

$$a/b = (A/B) (1/\overline{\cos^2 \delta}).$$

The smaller the dip angle interval and the nearer to zero, the smaller are systematic errors introduced by this method.

Let us quote finally two experimental results on fission angular distributions. Fig. 2 shows the angular distribution of the reaction  $^{238}\text{U}(\gamma, f)$  with a Bremsstrahl-

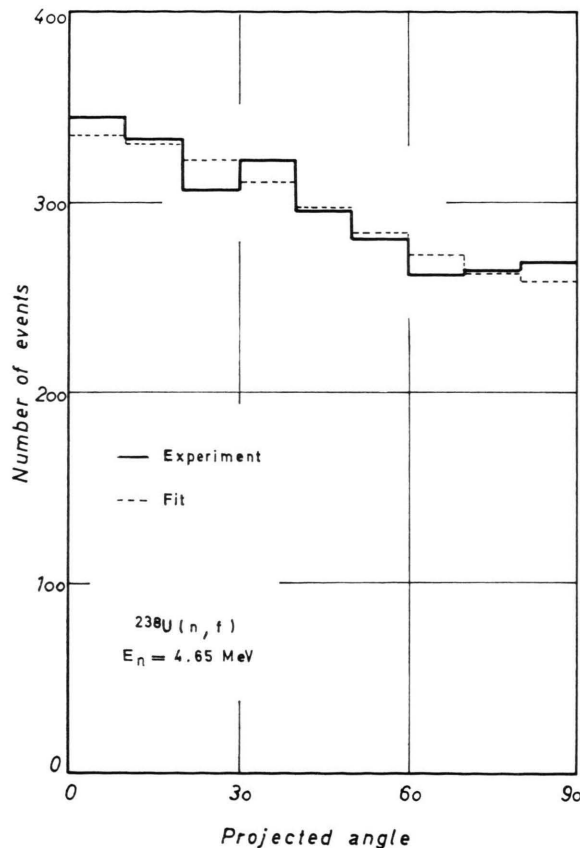


Fig. 3. Distribution of the projected angle  $\alpha$  for the reaction  $^{238}\text{U}(n, f)$ .

spectrum of 16.4 MeV maximum energy. The angle of incidence of the photons was parallel to a acetylcelluloid foil serving as detector. Some 4000 events with dip angle between  $5^\circ$  and  $20^\circ$  were observed. Analyzing the distribution in terms of

$$W(\Theta) = a + b \sin^2 \Theta$$

as outlined results in

$$b/a = 0.002 \pm 0.06,$$

i. e. isotropy. The error given is the statistical one, calculated from the error matrix. The value may be compared to

$$b/a = 0.09 \pm 0.14 \text{ at } 15.5 \text{ MeV}$$

peak Bremsstrahl energy, found by DE CARVALO et al.<sup>3</sup>

In Fig. 3 the angular distribution of fission products from  $^{238}\text{U}(n, f)$  for a neutron energy  $E_n = 4.65$  MeV is given. 2500 events were taken. Analyzing according to

$$W(\Theta) = a + b \cos^2 \Theta$$

yields

$$b/a = 0.32 \pm 0.07.$$

This is in close agreement with the figure

$$W(0^\circ)/W(90^\circ) = 1.24 \pm 0.03$$

found by HENKEL and SIMMONS<sup>4</sup> for a neutron energy of 4.50 MeV and

$$W(0^\circ)/W(90^\circ) = 1.23 \pm 0.03$$

given by EMMA et al.<sup>5</sup> for a neutron energy of 4.59 MeV. It should be mentioned that in the present experiments actually the two correlated fragments of binary fission were observed (the target was placed between two detector foils pressed together during irradiation and scanning)<sup>6</sup>. This allows to take more accurately the emission angle than on single tracks, and, very important, to eliminate fragments eventually scattered in the target.

In conclusion it may be stressed that the method proposed has the distinct advantages of simple and rapid collection of data and of reducing systematic errors to a minimum.

<sup>3</sup> H. G. DE CARVALHO, A. G. DA SILVA, and J. GOLDENBERG, *Nuovo Cim.* **19**, 1131 [1961].

<sup>4</sup> J. E. SIMMONS and R. L. HENKEL, *Phys. Rev.* **120**, 198 [1960].

<sup>5</sup> V. EMMA, S. LO NIGRO, C. MILONE, and R. RICAMO, *Nucl. Phys.* **63**, 641 [1965].

<sup>6</sup> H. GERHARDT, F. GÜNNENWEIN, H. HEINRICH, and H. HIPPEL, VI. Int. Conf. on Corposc. Photography, Florence 1966.