of polarization P of the μ^- meson prior to the transition under study. However in reality, no such isolated transitions take place in the μ-mesic atom. Previous transitions[5] lead to a depolarization of the μ^- mesons and therefore the formula given in reference 4 cannot be used for comparison with experiment. A calculation will show that it is also incorrect to take for P the residual degree of polarization in the 2p or 3d levels. Consequently it is necessary to consider the whole effect at once, as was done for example in the depolarization calculation.[5]

The mesic atom is formed by capture, from the continuum, of a μ^- meson with orbital angular momentum l_N. Thereafter, by successive emissions of Auger electrons and γ rays (the latter transitions are important since they proceed for low l), the μ^- meson cascades down to a level l_1 from which it proceeds to the level l_0 by emission of a circularly polarized γ ray. In such a process the angular distribution of the circularly polarized γ rays is given by

$$W = 1 + [3l_1(l_1+1)]^{-1/2} \times \left\{ l_1 \left[\frac{(2l_N+3)(l_N+1)}{(2l_N+1)^2} - \sum_{l=l_1+1}^{l_N} \frac{4l^2-5}{(4l^2-1)^2} \right] - \frac{(l_1+1)(2l_1-1)l_1}{(2l_1+1)^2} \right\} \tau F_1(1 l_0 l_1) P_0 \cos\theta, \quad (1)$$

where θ is the angle between the direction of emission of the circularly polarized γ ray and the direction of motion of the μ^- meson prior to capture into the orbit l_N (i.e., the direction of the beam); P_0 is the degree of the polarization of the μ mesons in the beam; and τ and F_1 are given in references 4 and 6.* The expression (1) was derived assuming a descending cascade $l_i = l_1 + i - 1$ $(i = 1, \ldots N)$. Corrections due to other channels are negligible.[5]

Setting $l_N = 14$, $l_1 = 1$, $l_0 = 0$ in expression (1) we obtain

$$W = 1 - 0.102\tau P_0 \cos\theta. \quad (2)$$

Equation (2) gives the required angular distribution of circularly polarized γ rays in a 2p → 1s transition in a μ-mesic atom.

*In reference 4 τ_1, τ_2 should be replaced everywhere by $-\tau_1$, $-\tau_2$.

[1] T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1671 (1957).

[2] Goldhaber, Grodzins, and Sunyar, Phys. Rev. **109**, 1015 (1958).

[3] A. Z. Dolginov, Nucl. Phys. **7**, 569 (1958).

[4] V. A. Dzhrbashyan, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 307 (1958), Soviet Phys. JETP **8**, 212 (1959).

[5] V. A. Dzhrbashyan, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1240 (1959), Soviet Phys. JETP **9**, 881 (1959).

[6] V. A. Dzhrbashyan, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 260 (1958), Soviet Phys. JETP **7**, 181 (1958).

Translated by A. M. Bincer
309

DEPENDENCE OF THE ANGULAR ANISOTROPY OF FISSION ON THE NUCLEAR STRUCTURE

A. N. PROTOPOPOV and V. P. ÉĬSMONT

Submitted to JETP editor December 29, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1573-1574

THE recently-obtained experimental data on the angular distribution of the fragments in the fission of various heavy nuclei induced by particles of 10 – 40 Mev made it possible to conclude[1-4] that a connection exists between the degree of anisotropy of the angular distribution $\sigma(0°)/\sigma(90°)$ and the parameter Z^2/A of the nucleus undergoing fission. This connection is characterized by a decrease of the degree of anisotropy with increasing value of the parameter Z^2/A.

A thermodynamical interpretation of this relation is attempted in the present work.* It is assumed that, for a sufficiently large excitation of the compound nucleus, the ratio of the cross section for fission at the angles of 0° and 90° to the direction of the incident particle varies qualitatively from nucleus to nucleus according to the known expression of statistical mechanics for the ratio of velocities of two competing processes:

$$\sigma(0°)/\sigma(90°) \sim \exp(\Delta E/T),$$

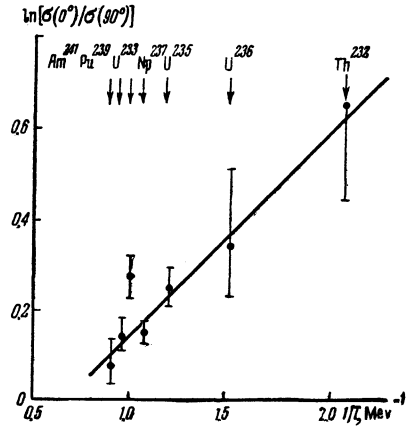
where ΔE is the difference of the activation energy of fission parallel and perpendicular to the beam, arising as a result of an interaction of incident particles with the target nucleus, and T is the temperature of the nucleus in the state of critical deformation. There are reasons for assuming that, for the nuclei considered below (far away from the nearest magic nucleus Pb^{208}), ΔE is independent of the structure of the target nucleus, but probably depends on the properties of the nucleus and particularly on its parameter Z^2/A, determining the cooling of the nucleus of the nucleus undergoing fission due to the evaporation of neutrons before the fission and to the loss of energy needed for producing the critical deformation. It seems probable that the last fact may be one of the causes of the dependence of the anisotropy on the structure of the nucleus.

In connection with the above, the temperature of various nuclei before fission, which is related to the excitation energy E by the expression[5] $T = 2(E/a)^{1/2}$ (where $a = 3.4(A-40)^{1/2}$ Mev^{-1}) was estimated. The effective excitation energy of a nucleus undergoing fission differs from the excitation energy of the compound nucleus (equal to the sum of the kinetic energy of the particle E_k and its binding energy E_b) by the value of the energy carried away by neutrons evaporated before fission E_{ev} and the energy lost for producing the critical deformation E_d:

$$E = E_k + E_b - E_{ev} - E_d.$$

According to the Hurwitz-Bethe hypothesis,[6] the energy E should be measured not from the ground state of the excited nucleus but from a certain characteristic level which is not influenced by the odd-even effects of protons and neutrons and the effect of filled shells. Therefore, in the determination of E, we used not the real values of E_b and E_d but the values calculated by formulae deduced from the liquid-drop model, neglecting the terms which take the effects of parity and shells into account. To determine the energy E_f, it is necessary to know the number of neutrons emitted by the excited compound nucleus before attaining the critical deformation stage. The estimate of the number of neutrons evaporated before the fission was based on the calculated relative probabilities of neutron emission and of fission.

The temperature of nuclei and the state of critical deformation were determined in the above way for the fission of Th^{232}, U^{238}, U^{235}, Np^{237}, Pu^{239} and Am^{241} induced by neutrons with energies from 14.3 to 14.8 Mev. Using the data of the references 1, 2, and 4, we plotted the dependence of $\ln[\sigma(0°)/\sigma(90°)]$ on $1/T$, as shown in the figure. The fact that the experimental data on the anisotropy fall on a straight line (within the limits of errors) indicates that $\sigma(0°)/\sigma(90°)$ really varies from nucleus to nucleus as $\exp(\Delta E/T)$, for ΔE = con-



stant, and that $T = f(Z^2/A)$. It seems therefore probable that the observed decrease of anisotropy with increasing parameter Z^2/A is, to a certain degree, connected with the fact that the temperature of a nucleus before fission increases with increasing parameter Z^2/A and, consequently, that the particles incident in the parallel direction are less important as a factor inducing fission.

*After concluding this work, the author became aware of the paper of Halpern and Strutinskii, presented at the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, September 1958, Paper P/1513). On the basis of the theory on the angular anisotropy of the fission presented there, the authors gave an explanation of the dependence of the anisotropy of the structure of the nucleus which, in certain respects, is similar to the one given here.

[1] R. L. Henkel and J. E. Brolley Jr., Phys. Rev. **103**, 1292 (1956).

[2] A. N. Protopopov and V. P. Éĭsmont, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 250 (1958), Soviet Phys. JETP **7**, 173 (1958).

[3] J. Halpern, Paper at the All Union Conference on Low and Medium-Energy Nuclear Reactions, Moscow 1957.

[4] Protopopov, Baranov, and Éĭsmont, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 920 (1959), Soviet Phys. JETP **9**, 650 (1959).

[5] V. Weisskopf, Statistical Theory of Nuclear Reactions, IIL, 1952.

[6] H. Hurwitz and H. A. Bethe, Phys. Rev. **81**, 898 (1951).

Translated by H. Kasha
310