Investigation of Nuclear Energy Levels by Measuring the Angle of Emission of the Reaction Products

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SIMPLE considerations based on the laws of the conservation of energy and momentum show that for the investigation of the energy levels of atomic nuclei it is possible to use a method permitting us to obtain information on the excited nuclear states by studying the angular distribution of the fissioning nuclei at a fixed direction of emission of the lighter particle, and not by measuring the energy of the light component of the reaction products, as it is generally done. This method was used for the study of the excited states of some light nuclei. The simultaneous registration of both particles was achieved with the aid of a coincidence system. Of the large number of problems associated with the investigation of the possibilities of the method under consideration, in the present paper we will discuss only its experimental realization and testing by studying the known reactions Be^9 (d,p) Be^{10} and Be^9 (d, H^4) Li^7

A beam of deuterons having an energy of 4.04 mev, obtained in the Moscow State University Cyclotron, after passing a system of diaphrams, was introduced on to the target. The transverse cross section of the beam on the target had the dimensions 2×3 mm. The current intensity in the beam was 5×10^{-8} A, the quantity of electricity per Faraday cylinder was registered by an integrator. The variation in energy did not exceed 40 kev. The protons and the α-particles, emitted as a result of reactions at the angle θ_2 to the direction of the incident beam, were registered by a proportional counter. The fissioning nuclei emitted from the target at an angle θ_3 to the direction of the incident beam were registered by an Allen type electron multiplier.[1] In order to avoid intensive overloading of the multiplier with foreign particles of low energy and with hard quanta of ultraviolet radiation, thin organic films were placed in front of the multiplier. The pulses of the proportional counter and of the electron multiplier were fed to the system of coincidences with a resolving time $\tau = 1 \times 10^{-6}$ sec. To attain a gradual change of the position of the counter and of the multiplier (angles θ_2 and θ_3) without distorting the vacuum, a "reaction" chamber was constructed with a mobile vacuum compressor of a special design.[2] The targets were prepared by evaporating (in a vacuum) powdery beryllium on organic films and dissolving the films in acetone. In order to avoid any considerable multiple scattering of the fissioning nuclei in the targets, the latter must by very thin and smooth. The thickness of the target in the experiments described here was $30 \pm 10\ \mu g/\text{cm}^2$ To obtain the required smoothness of the target, a procedure such as proposed in the paper by Il'chenko[3] was used.

The results of the investigation of the angular distribution of the fissioning nuclei in the reaction Be^9 (d, p) Be^{10} at $\theta = 35°$ are given in Fig. 1, where conventional units are plotted along the ordinate. The diaphram in front of the counter had the dimensions 4×4 mm, and that in front of the multiplier 20×2 mm. In order to remove the peaks corresponding to the elastic scattering of deuterons in the reactions (d, p) on the nuclei O^{16} and C^{12} (contamination), an aluminum foil was placed in front of the counter (for the exclusion of deuterons), and the total thickness of the organic film in front of the multiplier was selected such that the nuclei O^{17} and C^{13} would be absorbed. Use of the laws of the conservation of energy and momentum permits us to draw the conclusion that the peak at $\theta = 74°$ corresponds to the ground state of the Be^{10} nucleus and at $\theta = 52°$ to the first excited state (3.37 mev).[4] This second peak was found to be fairly broad, which is caused mainly by the γ-radiation of the fissioning nuclei and to a lesser degree by the multiple scattering of the fissioning nuclei in the target.

The angular distribution of the fissioning nuclei in the reaction Be^9 (d, He^4) Li^7 at $\theta_2 = 50°$ is shown in Fig. 2. The arrows with the notation Li^7, Li^{7*} and Li^{7**} give the position of the peaks corresponding to the ground and to the first two excited states of the Li^7 nucleus (0.48 and 4.61 mev) assumed in accordance with calculations. The obtained peaks relate to the ground and the first excited (0.48 mev) levels of the Li^7 nucleus. No peak corresponding to the level 4.61 mev[5] was detected with any noticeable intensity, which represents a direct substantiation of the fact that the Li^7 nucleus, having been produced in this state, disintegrates into the He^4 and H^3 nuclei. The above fact illustrates that the method of "angular emission" may be useful for the study of the relative intensities of γ-radiation and of the dissociation of excited nuclei.

In conclusion I consider it a pleasant duty to

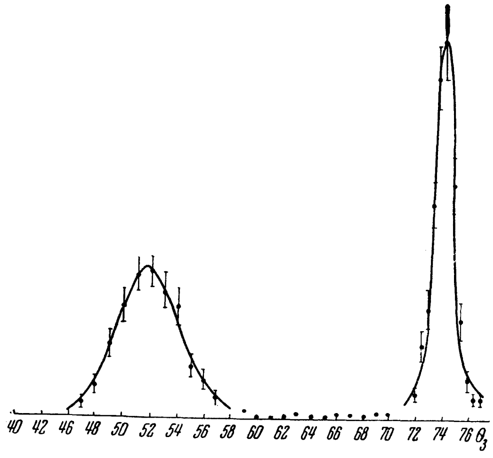

FIG. 1.

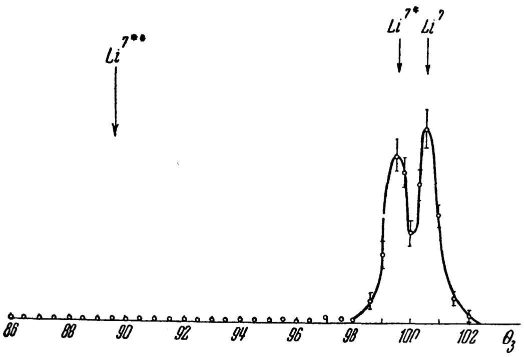

FIG. 2.

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Mean Excitation Energy of Fissioning Uranium Nuclei on Absorption of Slow π^--Mesons

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FISSIONING of uranium nuclei upon absorption of slow π^--mesons[1] may be considered as a fission induced by fast nucleons resulting from the interaction between a π^--meson and a pair of nucleons of the nucleus (n, p) or (p, p).* The fast nucleons produced may, in passing through a uranium nucleus, undergo collisions with the nucleus, giving rise to a nuclear-cascade process, and leave the nucleus in an excited state. The excited nucleus may lose energy by the evaporation of nucleons, undergoing fissioning at any of the stages of excitation. Thus, the fissioning on capture of slow π^--mesons in reality can be reduced to the fission of nuclei induced by fast nucleons, and a comaprison of the data characterizing the fission of U^{238} nuclei byslow π^--mesons and by protons of 140 mev energy represents great interest. Furthermore, the comparison provides a possibility of obtaining an evaluation for the mean excitation energy of the fissioning uranium nuclei on capture of slow π^--mesons.

In the Figure the distribution curves are given as a function of the paths of the single fragments for the fission induced by π^--mesons (crosses) and by protons with $E = 140$ mev (circles). There is good agreement between the two curves and they have one clearly expressed maximum. The coincidence of these curves, however, does not yet permit us to draw the conclusion that the mean excitation energies of the fissioning nuclei are equal in both cases, since in the region of comparatively larger mean excitation energies (from 80 to 160 mev) the shape of these curves does not change greatly.[4] It is significant that in fission by π^--mesons there is a single clearly expressed maximum, indicating that the mean excitation energy in this case is definitely higher than 50 mev. (It is known that for the energy of a falling nucleon 45 mev, the distribution curve of the single fragments for uranium has two additional clearly expressed maxima[5]).

An evaluation of the upper limit of the mean excitation energy for π^--mesons can be obtained by comparing the average number of charged evaporation particles per single fission: for slow π^--mesons [1] and for protons with $E = 140$ mev[4] these