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Photomesonic Fission of Bismuth*

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The fission of bismuth by high energy photons is detected by a photographic plate technique and some measurements on the cross section as a function of the photon energy are reported.

These suggest that the mechanism for fission is the generation of pions inside of the bismuth nucleus, and their subsequent re-absorption in the same nucleus in which they have been produced. This re-absorption generates high energy nucleons which produce the fission.

THERE is a good amount of evidence that heavy nuclei absorb gamma-rays with a sort of broad resonance around 20 Mev and a decreasing cross section at higher energies,[1] but, besides this purely electromagnetic process of energy absorption, there is evidence for another mechanism of energy transfer from a photon to a nucleus operative from about 140 Mev; namely, through the intermediate "production" of a meson in the nuclear matter of the nucleus. This meson may be re-absorbed in the nucleus in which it has been produced and when this occurs it provokes a nuclear reaction corresponding to a liberation of energy much larger than what can be transferred by the photon directly through a simple electromagnetic interaction.

Evidence of this is shown, e.g., in the photostars,[2] in the photodisintegration of the deuteron and in the production of high energy protons or neutrons by gamma-rays.[3–6]

We have studied another fairly typical example of this phenomenon, namely, the photofission of bismuth. By exposing Ilford emulsions loaded with bismuth in the beam of the Illinois betatron we have found the following excitation curve, Fig. 1, for fission. The details of the exposure are as follows: Emulsion 200μ thick of D1-type contains, according to Ilford, 0.27 of a gram of bismuth per cm^3 of emulsion, 1600 r of bremsstrahlung *at the plate* (measured with a Victoreen thimble ionization chamber, behind a flat sheet of $\frac{1}{8}$ in. Pb). The plates were developed with the usual Occhialini temperature procedure, omitting however the presoaking. The procedure started directly with Amidol developer at 3°C. The fissions were counted and recognized as such from the length of the track (16–26μ) and from the density and aspect of the tracks. Equally exposed D1 plates not loaded with bismuth did not show any appreciable number of fission tracks. Six series of exposures at betatron energies of 100, 150, 200, 250, 290, 319 Mev were made, and the fission cross section per equivalent quantum was obtained (Fig. 1). The data were then further analyzed, using the theoretical bremsstrahlung spectrum[7] and the cross section for fission as a function of the photon-energy was determined. The results are shown in Fig. 2.

These measurements, although admittedly crude, deserve some comments. In the first place, the fission cross section becomes appreciable around 150 Mev, i.e., not far from the pion production threshold and increases rapidly with energy. The curve shape also seems to suggest that fission occurs mainly by the mechanism outlined at the beginning of this article, and probably

TABLE I. Fission cross sections of bismuth.

Particle	Energy in Mev	σ_f in 10^{-24} cm^2	$\Gamma_f/\Sigma\Gamma$
p	300	0.05–0.08	0.05
d	200	0.15	0.11
α	300	0.45	0.32
x-rays	300	0.009	0.25

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[1] See, e.g., J. M. Blatt and V. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 651 ff.
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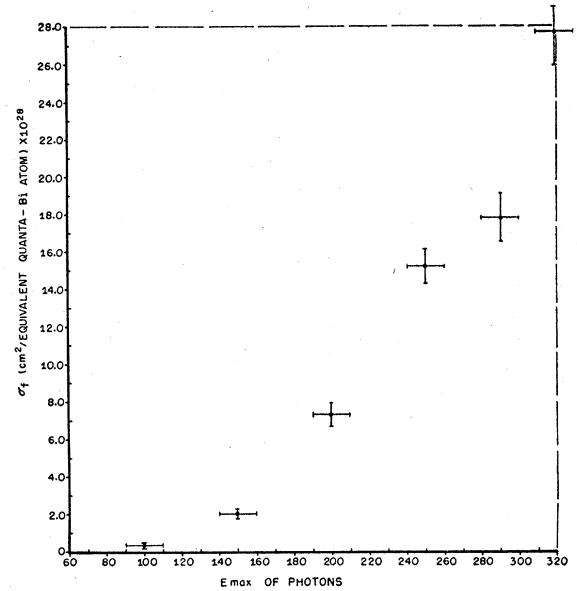

FIG. 1. Photofission excitation curve for bismuth.

with the contribution of the different kinds of mesons. The cross sections for the internal production of mesons is equal to σ'/p, where p is the escape probability of the meson from the nucleus, and σ' is the apparent production cross section, or the cross section for production of "free" mesons. If we try to make a more quantitative comparison, we may consider the point at maximum energy (310 Mev). The fission cross section σ_f can be estimated as

$$\sigma_f = A(\sigma_{\pi^0} + q\sigma_{\pi^\pm})(1-p)(\Gamma_f/\Sigma\Gamma),$$

where A is the mass number of bismuth (209), σ_{π^0}, $\sigma_{\pi^\pm}$ the cross sections for production of mesons on free nucleons, q is a correction factor which takes into account the fact that Pauli's principle, by preventing the nucleons to recoil into an occupied state, depresses the $\sigma_{\pi^\pm}$ meson production and $\Gamma_f/\Sigma\Gamma$ is the probability that the excited nucleus undergoes fission.

The values of σ_{π^0}, $\sigma_{\pi^\pm}$ are known roughly[8,9] and by integrating the differential cross sections, found by the investigations quoted above, we can estimate the σ_π. The factor q is near one as we can deduce from a comparison of photomeson production in carbon and hydrogen,[9,10] and p must be small as shown by the $A^{\frac{2}{3}}$ dependence of the photomeson production which indicates that photoproduction of mesons is a nuclear surface phenomenon.[10]

If we assume that the nucleus is fairly opaque ($p=0.2$) as suggested by the results of Littauer and Walker,[10] we arrive at the following crude estimate for σ_f:

$$\sigma_f = 209(1.5\times10^{-28} + 0.55\times10^{-28})0.8(\Gamma_f/\Sigma\Gamma)\ \text{cm}^2.$$

The experimental value is $(5\div10)\times10^{-27}$, which would give $\Gamma_f/\Sigma\Gamma \sim 0.25$. It is of interest to compare this number with the data on fission of bismuth induced by other high energy particles.[11]

Jungerman[11] finds the values reported in Table I for protons, deuterons, and α-particles. The geometrical cross section of bismuth is 2.35×10^{-24} cm² and σ_i(inelastic) for neutrons of 270 Mev is about 1.4×10^{-24} cm².[12] This last figure combined with σ_f, according to the relation $\sigma_f/\sigma_i = \Gamma_f/\Sigma\Gamma$, gives the numbers contained in the last column of Table I, except for the x-ray case.

We recognize that these evaluations of $\Gamma_f/\Sigma\Gamma$ are very crude indeed for several reasons, but we do not have, at present, better experimental data. For instance we lack reliable data on p, which seems to be considerably larger for 50-Mev mesons[13] than our assumption based on the direct results of Littauer and Walker.

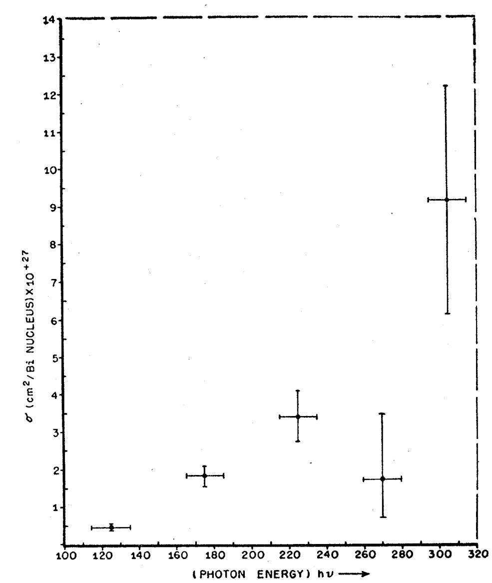

FIG. 2. Photofission cross section of bismuth as a function of the photon energy.

The order of magnitude of $\Gamma_f/\Sigma\Gamma$ for x-rays seems, though, to corroborate our interpretation of this effect, according to which the absorption of 300-Mev photons by bismuth is twofold: If it occurs on the surface it is often accompanied by meson-production, if it occurs in the interior, the mesons are mostly re-absorbed and accelerate a pair of nucleons to energies of the order of 100 Mev. The fission occurs when this pair of nucleons releases enough energy inside of the bismuth nucleus to produce fission with a mechanism similar to that accepted for fission produced by fast nucleons.[11]

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