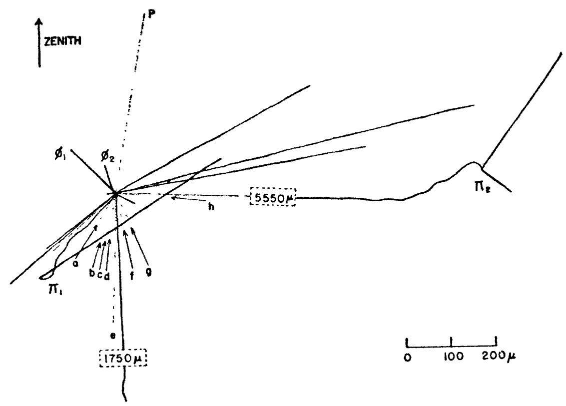

FIG. 1. Projection sketch of star, showing tracks due to: *P*, initiating particle; *a* to *g*, narrow-angle spray; *h*, another relativistic particle; π_1, π_2, slow π^--mesons terminating in stars; ϕ_1, ϕ_2, nuclear fragments. Number inside of each box denotes length in microns of portion of track omitted from drawing.

techniques.[9] Surrounding a narrow-angle spray, there appears fairly often a wider-angle shower of particles usually less energetic than those in the core.[10]

Bethe[11] has proposed a hypothesis to account for the simultaneous occurrence of wide-angle and collimated showers. He suggests that in a violent collision between nucleons, mesons can be produced either from the incident nucleon or from the target nucleon. The mesons arising from the incident nucleon might be emitted isotropically in the reference system of that particle, and mesons produced from the nucleon originally at rest may be isotropic in the system of that nucleon. The result in the laboratory frame of reference will be two groups of mesons, one collimated, the other spread out. Both will move predominantly into the forward hemisphere, for even the particles arising from the target nucleon, which move "backward" in the c.m. system, should usually, in the laboratory system, move in the general direction of the incident particle, though at larger angles with it than the core particles. If the incident nucleon is a proton, the collimated group is likely to have an excess of positive mesons, whereas no such excess (and perhaps even a π^--excess) might be expected for the wide-angle group.

In a 300μ Ilford G.5 emulsion exposed in the stratosphere[12] in Minnesota, we have observed an example of meson production in a high energy nuclear explosion which seems to fit the main features of Bethe's hypothesis. The star (reproduced as a projection sketch in Fig. 1)[13] shows: (1) a shower of eight tracks at minimum ionization, of which seven (*a* to *g*) form a relatively narrow downward spray, whereas the eighth (*h*) is emitted sidewise, at 96° with the zenith; (2) in the upper hemisphere, a single minimally ionizing track *P*, nearly collinear with the axis of the spray; (3) the characteristically scattered tracks of two slow π^--mesons (π_1, π_2) identifiable as negative by the secondary stars which they generate upon coming to rest; (4) ten dense "evaporation" tracks, including two due to heavy nuclear fragments (ϕ_1, ϕ_2), which display the usual "thin-down." These splinters emerge as a single fragment which breaks up into two after traveling 3μ.

From the number of dense tracks, the disintegration must have occurred in one of the heavier nuclei (Ag, Br, or I) in the emulsion. Of the two slow mesons, π_1 was emitted with an energy of 3.3 Mev, deduced from its range, and it generated a single charged secondary; π_2 had 18.4 Mev, and produced a two-prong star.

Track *P* and the narrow spray together form a "broom"[2] of roughly elliptic cross section, with *P* as the "handle." The major axis of the ellipse subtends 55° at the apex, the minor axis, 40°. The extension of *P* passes within 1° of the major axis, and 5° of the minor axis; i.e., it nearly coincides with the axis of the spray cone. Accordingly, there is little doubt that *P* is due to an incoming particle, probably a proton, which initiated the explosion. For the seven spray tracks, the average projected angle with their common axis is 14°; for the three tracks *h*, π_1, and π_2, the average angle with the same axis is 74°. In view of results by Fowler[7] and others, it is reasonable to attribute six to eight of the shower tracks to π-mesons, and the rest to protons.

We thus have a narrow-angle spray of five to seven relativistic mesons, and a wide-angle group of one relativistic particle and two slow π^--mesons. If a few additional fast mesons were emitted in the wide-angle group, these could be missed, since in a shower orientated like this one, the geometry discriminates against observation of the wide-angle tracks.[14] It will be seen that Bethe's hypothesis accounts rather satisfactorily for this event. By itself, the latter scarcely provides clear evidence, but considered together with Hornbostel and Salant's observations,[10] it lends plausibility to the two-group mechanism.[15]

Examples of single σ-mesons (slow, star-generating π^-) emerging from a star are not uncommon. On the other hand, observations of two σ-mesons from the same star are very rare.[16] This may be ascribed to two causes: (a) even the mesons in the wide-angle group are more likely to be fast than slow (our event is a somewhat special example in that the difference in velocities of the two meson groups is accentuated by the two slow σ's); (b) limitations of geometry.[14]

1 Brown, Camerini, Fowler, King, Muirhead, Powell, and Ritson, Nature **163**, 47 (1949).
2 J. Hornbostel and E. O. Salant, Phys. Rev. **76**, 468 (A) (1949); Osborne and Feld, Phys. Rev. **76**, 468 (A) (1949).
3 Leprince-Ringuet, Bousser, Tchang-Fong, Jauneau, and Morellet, Comptes Rendus **229**, 163 (1949).
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5 J. J. Lord and M. Schein, Phys. Rev. **77**, 19 (1950).
6 P. Freier and E. P. Ney, Phys. Rev. **77**, 337 (1950).
7 P. H. Fowler, Phil. Mag. **41**, 169 (1950).
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9 O. Piccioni, Phys. Rev. **77**, 1 (1950).
10 J. Hornbostel and E. O. Salant, Phys. Rev. **76**, 859 (1949).
11 H. A. Bethe, Proceedings of the Echo Lake Symposium (June, 1949), p. 123 ff, unpublished.

12 Balloon flight arranged by courtesy of ONR Project Skyhook.
13 Thanks are due Mr. F. W. O'Dell for this drawing.
14 When they are steep, near-minimal tracks are difficult to detect, and slow meson tracks are unlikely to terminate in the emulsion, and therefore are difficult to identify. The resulting discrimination affects a large fraction of the sprays which are most apt to be found in emulsions. Thus, if one observes, say, twice as many tracks in the core of a meson shower as in the surrounding portion, it is unsafe to conclude that a preponderant number of particles was actually emitted in the collimated group. Depending on the orientation of the shower cone, the two groups may in fact contain nearly equal numbers of mesons, as would be expected from Bethe's hypothesis.
15 That at least two of three mesons in the wide-angle group are negative is also consistent with Bethe's hypothesis. However, the presence of π^- and the absence of identifiable π^+ is adequately explained by the infrequent occurrence of slow π^+-mesons in stars, since even when they are born slow, they acquire considerable, velocity in passing through the Coulomb field, and thus emerge fast. It is noteworthy in this connection, that of 24 nascent σ-mesons observed by one of us (H.Y.) 17 are actually emitted *backward*, i.e., into the upper hemisphere.
16 In the only other example which has come to our attention there was no accompanying collimated spray. The latter, observed by E. O. Salant, is reproduced in F. Bitter's *Nuclear Physics* (Addison-Wesley Press, Cambridge), p. 89.

Some Properties of the 43-Day Isomer of Cd^{115}

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An activity of 43 days has been reported in cadmium.[1] The series of reactions[1] whereby it can be produced have identified it as an isomer of Cd^{115}. In the first investigation[1] of its properties, the activity was reported to decay by negatron emission, with a maximum beta-ray energy of 1.5 Mev, and a gamma-ray energy of 0.5 Mev. The early measurements also seemed to indicate that one gamma-ray accompanied each disintegration beta-ray.

A source of 43-day cadmium was prepared for the present researches when metallic cadmium was irradiated by slow neutrons in the Oak Ridge pile. The irradiated material was aged for more than a month to permit disappearance of any 2.5-day Cd^{115}. After this time, chemical separations were carried out for the removal of any lead, silver, antimony, or indium which might be present as

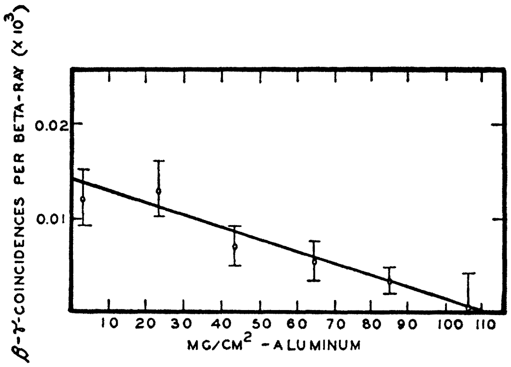

FIG. 1. Beta-gamma-coincidence rate of the 43-day cadmium as a function of the surface density of aluminum placed before the beta-ray counter.

radioactive contaminants. The beta-rays of the 43-day Cd^{115} were absorbed in aluminum. The absorption limit occurred at 600 mg/cm^2, corresponding to an energy of 1.41 Mev as calculated from Feather's equation.[2] An absorption curve in lead revealed the presence of two gamma-rays, having approximate energies of 0.10 and 2.0 Mev, the latter being of low intensity. A coincidence absorption curve gave a maximum gamma-ray energy of 1.10 Mev. It was also noted that the gamma-ray intensity was considerably less than one gamma-ray per beta-ray.

The results relating to gamma-rays were so markedly different from those of the earlier report that additional chemical purification was carried out for removal of any residual silver and indium. After completion of this chemical purification, the various absorption measurements on the beta-rays and gamma-rays were repeated. Two months had now elapsed since removal of the target material from the pile. The results were identical with those taken prior to the last chemical separation and one month previously.

A source of the highly purified Cd^{115} was placed in a beta-gamma-coincidence counting arrangement, and the beta-gamma-coincidence rate was observed as a function of the surface density of aluminum placed before the beta-ray counter. These data are shown in Fig. 1, where the beta-gamma-coincidence rate is observed to decrease from 0.014×10^{-3} coincidence per beta-ray at zero absorber thickness to zero at 110 mg/cm^2, indicating the presence of an inner beta-ray spectrum having a maximum energy of 0.38 Mev which is coincident with gamma-radiation. The harder beta-spectrum of 1.41-Mev maximum energy apparently leads to the ground state of the residual nucleus.

Assuming that on the average each beta-ray of the inner spectrum is followed by 1.10 Mev of gamma-ray energy, the calibration of the gamma-ray counter indicated that only one percent of the total beta-radiation is contained in the group of maximum energy 0.38 Mev.

A gamma-gamma-coincidence rate of 0.07×10^{-3} coincidence per gamma-ray was observed in Cd^{115}, showing that gamma-rays are present in cascade.

Bell, Cassidy, and Hughes of the Oak Ridge National Laboratory have independently reached conclusions similar to ours. Using a coincidence spectrometer employing scintillation counters, they find gamma-rays at 1.29, 0.93, 0.72, 0.50, 0.198, and 0.074 Mev and that 0.7 percent of the beta-rays are coupled with gamma-rays. They have also demonstrated that the gamma-ray at 2 Mev is associated with an impurity. Assuming that each beta-ray of the inner spectrum is followed by 1.29 Mev of gamma-ray energy, the beta-gamma-coincidence rate observed by the writers indicates that 0.85 percent of the total beta-radiation is contained in the low energy spectrum.

* Guest physicist, Bartol Research Foundation (1950). At present at University of Aligarh, India.
† Assisted by the joint program of the ONR and AEC.
[1] Seren, Engelkemeir, Sturm, Friedlander, and Turkel, Phys. Rev. 71, 409 (1947).
[2] N. Feather, Proc. Camb. Phil. Soc. 34, 599 (1938).

Energy Barrier for Asymmetric Fission in the Static Liquid Drop Model

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August 24, 1950

WE have attempted to calculate the fission barrier for U^{236} by two approximate methods. As a first approximation a model was chosen which consisted of two tangent spheres of arbitrary radii joined by a frustrum of a cone which was tangent to each sphere. This configuration gives the sum of Coulomb and surface energies as 7.32 Mev greater than the parent nucleus if equal radii are chosen for the spheres. When the ratio of the radii is seven to eight (approximately a splitting in mass of two to three as is observed), the above energy is increased by 0.2_6 Mev. These results utilize 532.0 Mev for the surface energy and 799.8 Mev for the Coulomb energy of the U^{236} nucleus in agreement with Frankel and Metropolis.[1] Since the symmetric shape is quite similar to that given by the above authors, we feel that the barrier against asymmetric fission at the true saddle point should be of the above order of magnitude.

The second model used an arbitrary ellipsoid of revolution which was subjected to a deformation. We took the deformation to be:

$$r=a(\beta^2-\mu^2)^{\frac{1}{2}}\Sigma_l c_l\mu^l. \tag{1}$$

Here r is measured along the radius of the ellipsoid, R, in units of its major axis, a, μ is the cosine of the angle between R and a, and

$$\beta^2=a^2/(a^2-b^2), \tag{2}$$

where b is the minor axis of the ellipsoid. The C_l's are constants to be determined so that the deformation energy is a minimum. An expansion in powers of r/R permitted calculation of the surface energy, the mutual Coulomb energy between the deformation and the ellipsoid, and finally the self-Coulomb energy of the deformation to the order $(r/R)^2$. In this manner we obtained a quadratic expression for the deformation energy, ΔE, in terms of the C_l's for a given β. The energies were calculated as far as $l=4$, and in principle could be extended to higher l values without fundamental difficulty.

The equations

$$\partial\Delta E/\partial C_l=0, \quad l \text{ even} \tag{3}$$

together with the constant major axis condition

$$\Sigma_{l\text{ even}}\, C_l=0 \tag{4}$$

and the demand of zero volume change

$$\int_{-1}^{+1}(R^2r+Rr^2)d\mu=0 \tag{5}$$

determine the extremal values of the C_l's. This procedure does not determine the extremal values for odd l, since the corresponding C_l's enter only in second order in ΔE or condition (5).

For the choice $\beta^2=1.27$, $a/b=2.17$, the following minimal values of the C_l's were obtained: $c_0=-0.04558$, $c_2=+0.23567$, $c_4=-0.19009$; and these give $\Delta E=-1.0_2$ Mev. The difference in energy between this ellipsoid and the parent nucleus of the same

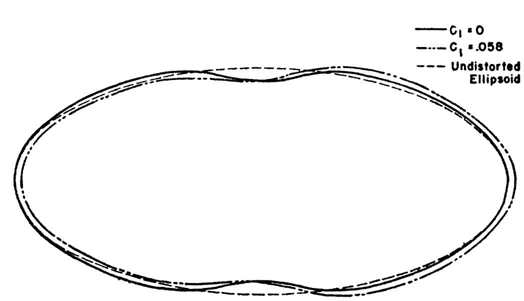

FIG. 1. Minimum energy configurations on the ellipsoid model for $\beta^2=1.27$.