were observed from the helium, although the total number of counts was small (~120).

The observed spectrum from process (c) differs markedly from that calculated on phase space considerations alone, possibly because of the interaction of the outgoing neutrons. Process (d) is energetically possible; however, the yield is expected to be small, since energy available for the π^0 is small and selection rules require that the π^0 come off in the p state with respect to the two neutron system (assuming parity of π^0 same as π^- and capture from the S-state).

We wish to thank Mr. J. Vale and the cyclotron crew for providing the bombardments.

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[1] Panofsky, Aamodt, and York, Phys. Rev. **78**, 825 (1950).
[2] Panofsky, Aamodt, Hadley, and Phillips, Phys. Rev. **80**, 94 (1950).
[3] Johnston, Bozman, Rubin, Swanson, Corak, and Rifkin, MDDC 850, unpublished.
[4] Crandall, Moyer, and York (private communication).

On Advanced and Retarded Potentials

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WHEELER and Feynman[1] in their absorber theory of radiation have attempted to circumvent the classical infinities of point charges by introducing retarded and advanced potentials of interaction on an equal footing. Their theory has provoked much (unpublished) favorable as well as adverse comment. In view of the importance of the question whether a description of nature using advanced forces of interaction at a distance is possible, the following purely critical remarks may not be out of place.

That there are doubts about the consistency and physical applicability of the W-F theory is due to the dynamical incompleteness of the Maxwell-Lorentz theory, with fields determined by the world-lines of the charges, although the latter may be guided not only by self- and mutual electrodynamic forces and inertia but also by external forces, electromagnetic or mechanical, chosen at will, in short, by the arbitrary intervention of an experimenter. That the present motion of particles on a star 50 light years away should *actually* depend on whether a person on the earth arbitrarily will or will not decide to push a button in the year 2000 seems absurd, at least to our customary way of thinking. Closer analysis of the word "actually" shows that it could mean that the behavior of particles on the star in $(1950+n)$ for various n's shows a dependence on whether some one does or does not push a button on the earth in $(200+n)$ as established *post factum*. An "actual" dependence of the year 1950 on the year 2000 as confirmed by observation does not seem so absurd any more. It is quite a different question, however, whether waves converging on the "cause" are empirically acceptable. To reconcile us with this special form of retroaction, W-F wish to exclude arbitrary abrupt interventions, such as observers pushing buttons. They admit only built-in continuous mechanisms (W-F, II p. 427) which thereby become parts of the system itself. Thus they restrict their theory to closed deterministic systems in which "the distinction between cause and effect is pointless. The stone hits the ground because it was dropped from a height; equally well, the stone fell from the height because it was going to hit the ground" (W-F, II p. 428). The exclusion of arbitrary intervention, usually called an experimental test, for the sake of permitting a description by advanced and retarded potentials looks like a flight into unreality, however.

Wheeler and Feynman's reply to this objection is that their absorber theory permits a *consistent* derivation of the *tested* results of the usual retarded theory. In particular, they point out that the well known self-force experienced by a particle a under an acceleration (which may also be represented by Dirac's antisymmetric expression

$$F^a(a)=\tfrac{1}{2}[F^a{}_{\text{ret}}(a)-F^a{}_{\text{adv}}(a)],) \tag{1}$$

can be derived from the symmetric sum of half-advanced, half-retarded forces produced by the particles k other than a:

$$F^a(a)=\tfrac{1}{2}\Sigma_{k\neq a}[F^k{}_{\text{ret}}(a)+F^k{}_{\text{adv}}(a)]. \tag{2}$$

The equivalence of (1) and (2) which is the central point of W-F's theory rests on two assumptions, namely, *first*, that the body of all particles constitutes a "perfect absorber" characterized by the equation [W-F, I (37)]:

$$\Sigma_{\text{all }k}F^k{}_{\text{ret}}(P)=\Sigma_{\text{all }k}F^k{}_{\text{adv}}(P) \tag{3}$$

valid in all world points P including those of a particle; *second*, that the following initial conditions hold at the place of particle a at the instant when a alone is accelerated (by any test force whatsoever):

$$\tfrac{1}{2}\Sigma_{k\neq a}F^k{}_{\text{ret}}(a)=0, \tag{4}$$

although

$$\tfrac{1}{2}\Sigma_{k\neq a}F^k{}_{\text{adv}}(a)\neq 0. \tag{4'}$$

The left-hand side of (4′) then is identical on the one hand with (2), and on the other hand with (1), by virtue of (3) and (4), thus proving the equivalence of (1) and (2).

Now, although there is no mathematical contradiction between the assumptions (3), (4) and (4′), nevertheless the following physical objection against the simultaneous validity of (3) and (4), (4′) at the time of acceleration of a may be raised. Equation (4) implies that before and at the instant $t=0$ when particle a is accelerated, the other particles are in a state of disorder so that their retarded force contributions which arrive in a at $t=0$, average out to zero. At times $t>0$, however, the other particles are affected by what happens to a at $t=0$ and thus yield a non-vanishing advanced contribution (4′) arriving at a at $t=0$. The privileged rôle of particle a at $t=0$ leads to the unsymmetric initial conditions (4) and (4′). The absorber hypothesis (3), however, implies and can be accepted only (a) when all particles are on an equal footing, thus excluding any privileged part played by the particle a, and (b) when we are assured that no particle has, or ever will be, subjected to an arbitrary disturbance; otherwise (3) would be self-contradictory, as is shown by the example of keeping all particles at rest before $t=0$, and on prescribed paths after $t=0$. Thus, although (3) alone, or (4) and (4′) alone may be acceptable, it is physically *inconsistent* to couple the symmetric assumption (3) with the asymmetric initial conditions (4), (4′). It seems that other ways will have to be found in order to get rid of the classical infinities of point charges.[2]

[1] J. A. Wheeler and R. P. Feynman, Rev. Mod. Phys. **17**, 157 (1945), Bohr commemoration number; Rev. Mod. Phys. **21**, 425 (1949), Einstein number. Referred to as W-F, I and II.
[2] We mention in this connection M. Born's theory of reciprocity, Rev. Mod. Phys. **21**, 463 (1949), Einstein number; also A. Landé, Phys. Rev. **76**, 1176 (1949); **77**, 814 (1950).

Collimated and Wide-Angle Meson Groups in a Hard-Shower Star

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SPRAYS of relativistic particles associated with cosmic-ray stars have been observed in ultrasensitive photographic emulsions by many workers.[1–6] These sprays are now known to consist principally of π-mesons,[7,8] and they can be identified with the penetrating showers observed in cloud chambers and with counter

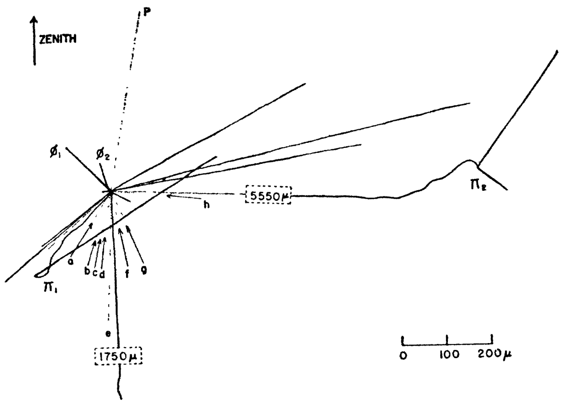

FIG. 1. Projection sketch of star, showing tracks due to: P, initiating particle; a to g, narrow-angle spray; h, another relativistic particle; π_1, π_2, slow π^--mesons terminating in stars; ϕ_1, ϕ_2, nuclear fragments. Number inside of each box denotes length in microns of portion of track omitted 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).
4 Brown, Camerini, Fowler, Heitler, King, and Powell, Phil. Mag. **40**, 862 (1949).
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).
8 Camerini, Fowler, Lock, and Muirhead, Phil. Mag. **41**, 413 (1950).
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