TABLE I. Q values for the alpha-particle groups from fluorine.

Proton Energy (kev)	Group α_1 932	867	665	Group α_2 932	867	665
Q by magnetic deflection (Mev)	1.95	1.94	1.97	0.96	1.19	0.98
Q by range (Mev)	1.88	1.92	1.93	—	1.17	0.96
Mean Q (Mev)	1.92	1.93	1.95	0.96	1.18	0.97
Error (Mev)		±0.08			±0.08	

TABLE II. Ratio of the intensities $^{\alpha}1/\alpha_2$ of the two alpha-particle groups and the gamma-ray intensity ratio observed by Rasmussen, Hornyak, and Lauritsen.

Proton Energy (kev)	343	594	665	867	932
$^{\alpha}1/\alpha_2$	50	>60	6	3.0	3.7
$^{\gamma}1/\gamma_2$				2.5	3.3

gamma-ray intensity ratio observed by Rasmussen, Hornyak and Lauritsen.[2] The variation in $^{\alpha}1/\alpha_2$ with proton energy is predicted by the varying penetrability of the barrier of the O^{16*} nucleus for the two alpha-particle groups except in the case of the 594-kev resonance, for which the α_2 group could not be distinguished above background and appears to be forbidden.

In the work with lithium, Walker and McDaniel show that there are gamma-ray lines of energies 14.8 and 17.6 Mev, and give evidence that these lines correspond to transitions in the excited Be^8 nucleus formed in the reaction

$$Li^7+H^1\rightarrow Be^{8*}\rightarrow Be^8+\gamma.$$

The emission of a 17-Mev gamma-ray leaves the Be^8 nucleus in its ground state, while that of a 14-Mev gamma-ray could leave the nucleus in the well-known 2.8-Mev excited state, which has been observed in several other reactions and is known to break up into two alpha-particles.[9] We have observed these particles by bombarding a thick target of the Li^7 isotope (oxidized by exposure to air) with 440-kev protons. Figure 2 shows the distribution of alpha-particles emitted from this target, together with a curve taken with a Li^6 target under the same conditions. The alpha-particles from the excited state of Be^8 form a group centered at an energy of 1.38 ± 0.08 Mev. This group was found to have an excitation function agreeing exactly with that of the gamma-radiation for proton energies between 350 and 700 kev. The energy of the excited state of Be^8 from these measurements is 2.6 ± 0.2 Mev, and the width is 0.9 ± 0.1 Mev. The higher energy group shown in Fig. 2 (Li^7) could be due to contamination of the target by Li^6 and check experiments showed that the number of particles in this group was only about twice that expected from the contamination; within the limits of accuracy of the comparison, the whole of the second group could be ascribed to the $Li^6(p\alpha)He^3$ reaction.

We wish to thank Sir John Cockcroft and Dr. W. D. Allen and members of his group at the Atomic Energy Research Establishment, Harwell, who provided the lithium targets used.

[9] Bonner, Evans, Malich, and Risser, Phys. Rev. **73**, 885 (1948).

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Photograph of a Shower Produced by a π-Meson and a π-μ-Decay

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THE production of multiple heavy particles by the interaction of π-mesons with nuclei has been definitely established by the recent investigation with photographic plates by the Bristol school.[1] So far little evidence of such interactions has been obtained from Wilson Chamber photographs. We reproduce herewith a photograph of a shower which appears to be produced by the interaction of a π-meson with a nucleus; the particles emitted are not heavy in character, neither have they short ranges like the particles recorded in photographic emulsions (see Fig. 1). The photographs are stereoscopic and careful reprojection shows that the shower starts from a point in the gas of the chamber about 1.5 cm below the second lead plate (thickness 2.5 cm). Altogether seven particles are present in the shower and the two horizontal particles ejected towards the left start from the same point as the other five particles contained in the downward cone. These five particles pass out of the third lead plate (thickness 1 cm) with only one more secondary particle as the numbering of the tracks will show. The track No. 7 is an old track which is easily recognized from its diffused nature.

The first interesting point about the shower is its generation in the gas apparently from a point and the emission of the two particles toward the left without any apparent emission on the right

[1] Lattes, Occhialini, and Powell, Nature **160**, 486 (1947).

TABLE I. Range and energy of the particle P before entering the third lead plate of thickness one centimeter.

Nature of particle	m_0	β^2	E	Range in lead
π	1.6×10^8 ev	0.56	2.05×10^8 ev	1.01 cm
μ	1.0×10^8 ev	0.39	1.48×10^8 ev	1.96 cm

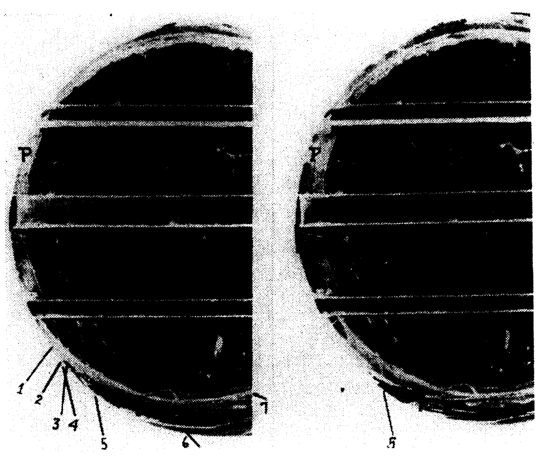

FIG. 1. Photograph of a shower which appears to be produced by the interaction of a π-meson with a nucleus.

side. If these are electrons they will carry negligible momentum, but otherwise conservation of momentum would require the emission of one or more neutral particles on the right side. Production of a pair of tracks in the gas of the chamber has been reported before by Rochester and Butler[2] but the present photograph is completely different from theirs.

Of the five particles contained in the downward cone, the fourth from the left (or second from the right) shows a large increase in ionization on passing out of the third lead plate (thickness 1 cm). This track is noted as No. 5 on emergence. It is clearly seen that track No. 5 has suddenly changed its direction and there is a considerable fall in ionization from the point at which it has changed its course. We shall see from the arguments given below that this particle is a π-meson and the sudden change in ionization and direction represents a π-μ-decay and not a μ-electron decay. Moreover, it is most probable that the shower has been produced by the interaction of this meson with a nucleus.

As there was no magnetic field in the chamber, the only method available for measuring the energy of the primary particle P is from the mean angle of scattering in the lead plates. The measurement of energy in this way is subject to the limitation that instead of determining the mean angle of scattering obtained from a large number of scattering observations, only the scattering angle in a single case is introduced in William's[3] equation. The discrepancy between the actual scattering angle (as observed) from the mean of a large number of similar observations will be small when the thickness of the scattering medium is fairly large. In our case the thickness is 1–2.5 cm of lead, which is large compared to the track length of multiply scattered particles observed in photographic plates.

The mean scattering angle of the incident particle in the second lead plate (thickness 2.5 cm) in the chamber is $0.7°\pm0.1$. This gives the total energy of the particle P as 2.04×10^9 ev, from William's formula.[3] The mean angle of scattering of track No. 5 (which we assume to be continuation of P) in the third lead plate (thickness 1 cm) in the chamber has been found to be $11°.3\pm0.3$ from which the total energy E of the particle *before entering this plate* comes out to be $E\beta^2=0.8\times10^8$ ev. This particle may be either a π- or a μ-meson. The value of β^2 was found out from the relation $E=m_0c^2/(1-\beta^2)^{\frac{1}{2}}$ and the above value of $E\beta^2$ for two values of m_0, those of π- and μ-mesons. The results, as obtained from Rossi and Griessen's curves, are given in Table I. From the values of the range it is evident that if the particle P were a μ-meson it would have sufficient kinetic energy to pass out of the chamber even after passing through 1 cm of lead, whereas if it were a π-meson it should stop just on emergence from the lead plate, and this is what has happened in our photograph. We may therefore conclude that the track P is that of a π-meson which has reached the end of its range and then decayed into a μ-meson. We believe this is the first cloud-chamber evidence of a π-μ-decay.

The next remarkable point is the scattering of track No. 6 in the gas. The scattering angle in the gas is about 16° and $2.9°\pm0.2$ in the lead plate above. The total energy of the particle before entering the plate is therefore 3.3×10^8 ev assuming its rest mass to be 10^8 ev. The particle is thus found to be too energetic to stop in the chamber and the sudden change in its direction must be attributed to nuclear scattering. No other particle has been emitted from the nucleus which is simply excited. One such case has been reported by Bhabha and Daniell[4] from photographic plate observation.

The particles constituting the shower do not appear to be electronic in nature as they do not multiply in the third lead plate. Moreover, the probability of emission of so many electrons in one single act from a point in the gas is negligibly small.

[2] G. D. Rochester and C. C. Butler, Nature **160**, 855 (1947).

[3] E. J. Williams, Proc. Roy. Soc. **169**, 531 (1939).

[4] H. J. Bhabha and R. R. Daniell, Nature **161**, 883 (1948).

The energy of the incident particle has been found to be 2.04×10^9 ev. We have assumed before that the π-meson referred to above (i.e., track No. 5) is the continuation of this incident particle. On this basis we find that the particle has lost an energy $(2.24\times10^9-2.05\times10^8)=1.835\times10^9$ ev in the interaction that has produced the shower. Excluding the incident particle there are then six particles in the shower and on an average, energy available for each is about 3.1×10^8 ev. We have seen that the total energy of one of the particles, i.e., particle No. 6 is 3.3×10^8 ev which gives support to our assumption. Though conservation of energy has been fulfilled, conservation of charge requires that three pairs of oppositely charged particles have been emitted, since it is very difficult to identify any of the tracks as due to a broken part of the nucleus. We therefore conclude that the shower is produced by a π-meson interacting with the nuclear field of another nucleus, the process being analogous to the phenomenon of scattering as visualized by Heitler and Peng[5] in which more than one meson can be emitted in a single interaction. The average total energy of each of the particles emitted in the process is about 3.1×10^8 ev. The ionization produced by a particle of this energy should be perceptibly more for a π-meson than for a μ-meson. Hence they appear to us to be more like μ-mesons than π-mesons as they produce less than the expected ionization for π-mesons. According to Occhialini and Powell,[6] however, π-mesons are first emitted in such an interaction, which then decay into μ-mesons. We cannot, however, exclude the possibility that they are π-mesons since the energy available for each of them is 3.1×10^8 ev, which is well above their rest mass.

The author is indebted to Professor D. M. Bose, Director, Bose Institute for very helpful and stimulating discussions.

[5] W. Heitler and H. W. Peng, Proc. Camb. Phil. Soc. **38**, 296 (1942).
[6] G. P. S. Occhialini and C. F. Powell, Nature **162**, 168 (1948).

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On the Origin of High Energy Photons

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RECENT experiments concerning mixed showers and extensive air showers suggest the simultaneous production of electronic and mesonic components by a nucleon-nucleon collision. The origin of such electronic component may, as pointed out by Oppenheimer,[1] be attributed to the disintegration photons of neutral mesons which are believed to have a very short life. But this interpretation, though of great interest, seems to lead to the following difficulties.

(1) The disintegration photons of the neutral mesons produced in a thick lead block at high altitude would give rise to cascade showers, but Schein *et al.*[2] observed only very few such showers in their high altitude experiment.[3] (2) Disintegration photons should have as large an angular divergence as mesons produced. But this expectation could be confirmed neither by the direct cloud-chamber observations, that the electron showers observed in mixed showers have always smaller angular divergence than mesons simultaneously produced,[4] nor by the analysis of extensive air showers that they have never multiple cores.[5] (3) The number of mesons produced in one collision is believed to be several or more and at least one-third of them should be neutral as concluded from the theory of nuclear forces. This would result in that *every* meson shower should be accompanied by multiple electron showers. Even when only one neutral meson is produced there would be two or more cores of electron showers since it disintegrates into at least two photons. The experiment by a cloud chamber operated with random expansion, however, shows that only one or two meson showers in several tens are accompanied by electron showers.[6] Even in a controlled chamber, which will certainly be favorable to mixed showers, not all meson showers contain cascade showers.[4,7] Further, almost all of them have a single core and only very few have double cores.[4]

Beside experimental evidences mentioned above,

[1] Lewis, Oppenheimer, and Wouthuysen, Phys. Rev. **73**, 127 (1948).
[2] Schein, Jesse, and Wollan, Phys. Rev. **59**, 615 (1941).
[3] M. Taketani, Symposium on Meson Theory (1943).
[4] H. Bridge and W. Hazen, Phys. Rev. **74**, 579 (1948).
[5] Robert W. Williams, Phys. Rev. **74**, 1689 (1948).
[6] Ralph P. Shutt, Phys. Rev. **69**, 261 (1946); Wilson M. Powell, Phys. Rev. **69**, 385 (1946).
[7] William B. Fretter, Phys. Rev. **73**, 41 (1948); C. Y. Chao, Phys. Rev. **74**, 962 (1948).

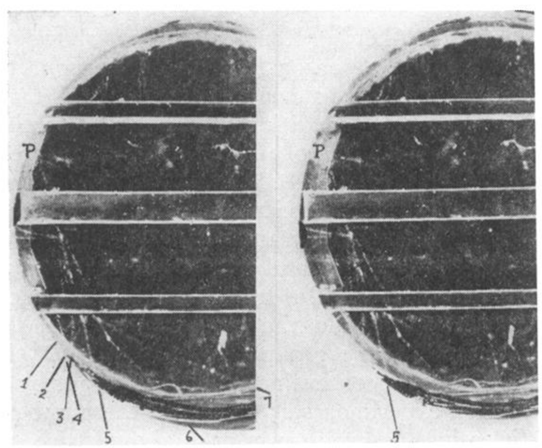

FIG. 1. Photograph of a shower which appears to be produced by the interaction of a π-meson with a nucleus.