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.

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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,

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recent calculation on the life of the neutral meson shows that the life is so long that the simultaneous production of electronic component would hardly be observed in the cloud-chamber experiment.[8]

Now we must look for another cause of the production of the electron component appearing in mixed showers as well as extensive air showers. Tomonaga and the present author have once attempted to attribute this soft component production to the production of photons by the charge acceleration taking place in nucleon-nucleon collision.[9] The proposed mechanism is solely based on the electromagnetic interaction, the theory of which is trustworthy up to the region of extremely high energy. We concluded that, although other possibilities could not be excluded, at least a considerable part of air showers would have such an origin. When a charged particle with a velocity uc is stopped, photons with energy between ϵ and $\epsilon+d\epsilon$ are emitted by the acceleration. The probability for this emission can be estimated simply by picturing the phenomena in the following way: The Lorentz contracted Coulomb field attached to the particle is liberated as photons at the instant of the collision. This probability is found to be[10]

$$\frac{1}{137\pi}\left(\frac{1}{u}\ln\left(\frac{1+u}{1-u}\right)-2\right)\frac{d\epsilon}{\epsilon} \approx\frac{1}{137\pi}\left(\ln 4\left(\frac{E}{Mc^2}\right)^2-2\right)\frac{d\epsilon}{\epsilon}, \quad (1)$$

where M and E mean the mass and energy of the incident particle. The same can be concluded also when a charge begins suddenly to move. Such a charge acceleration occurs also when an energetic proton or neutron converts into neutron or proton by the collision with a matter nucleus. The same effect will also be expected for each of newly produced mesons if the mesons are produced in the collision. In order that this simple picture be applicable, however, two conditions must be satisfied: (1) the process must take place sufficiently suddenly, and (2) there should be no interference between processes taking place at different nucleons in the collided nucleus. The first condition requires that the time of collision should be shorter than the period of the photon emitted. If the collision time is longer the process goes on adiabatically and no emission of light will take place. Denoting by r the impact parameter and by ξ the Lorentz factor for the particle, this condition requires that $r/\xi c<\hbar/\epsilon$, or $\epsilon<\xi\hbar c/r$ which gives the upper limit of the spectrum of the emitted photons. The second condition requires that the wave-length of the emitted photon should be shorter than the mean distance $\bar{r}$ between nucleons in the nucleus: $\epsilon>\hbar c/\bar{r}$, which limits the long wave side of the spectrum. The total probability of emission of photons in such a collision is now obtained by integrating (1) over ϵ from $\hbar c/\bar{r}$ to $\xi\hbar c/r$ and averaging over the impact parameter r. Assuming that $r_{\min}\approx\hbar/Mc$, $r_{\max}\approx\hbar/\mu c$, and $\bar{r}\approx\hbar/\mu c$, μ being the mass of the meson, we find the probability is approximately

$$\approx 4.7\times10^{-3}(\ln\xi)^2. \quad (2)$$

The emission of photons by newly produced mesons is improbable because the wave packet of the mesons produced multiply and cannot be smaller than $\hbar/\mu c$ so that the interference effect mentioned above cannot be neglected. The total probability of the emission of the photon in the nuclear collision is given by multiplying (2) by $A^{\frac{1}{3}}$, A being the atomic weight, and further by a factor k, the probability of the nuclear collision in which the proton→neutron or neutron→proton conversion takes place:

$$\approx kA^{\frac{1}{3}}\times4.7\times10^{-3}(\ln\xi)^2. \quad (3)$$

Though little is known about the factor k, we may suppose that it is not much smaller than unity. Then the value of (3) may be sufficient to explain the observed frequency of the accompaniment of electron showers by meson showers.

The above mechanism of soft-ray producing process can be responsible for the production of air showers and seems to be able to explain some experimental facts which could not be accounted for by the ordinary electron-primary hypothesis, e.g., the height of maximum shower frequency and the angular distribution.[11] A considerable part of the bursts under thick absorbers at high altitude will also be due to soft-rays produced by nucleons by the same mechanism, while at lower altitude they are mainly due to electromagnetic processes (e.g., bremsstrahlung and knock-on process) by mesons.[12] Because the nucleon component of the cosmic rays increases with altitude more rapidly than the meson component, the bursts produced by the former predominate over those by the latter at about 7-m water depth. The fact that the observed frequency-altitude relation of this phenomenon shows a much steeper increase at higher altitude than the increase of the meson component is accordance with this view.[13]

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