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On Pair Production by Scattering of the γ-Ray

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(Read April , 1935)

§1. Introduction

When the high energy radiation passes through matter, its energy is ~~lost~~ dissipated by various processes such as ionization, radiative collision, Compton scattering, materialization etc. The probability of occurrence of these processes were ~~calculated~~ obtained by performing the calculation to the second approximation in Born's theory of collision. The results ~~of these calculation~~ obtained were not fully in accordance with the experiment, so that the applicability of the present form of the quantum mechanics to the high energy radiation became doubtful.†

Now owing to the importance of the collision problem for ~~of~~ the high energy radiation, it will not be meaningless to carry through the calculation to the third approximation. If the probability of occurrence of the third order process ~~be~~ were found to be

†

(b) Pair production ~~in~~ by the absorption ~~scattering~~ of a photon, another photon being scattered at the same time.

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comparable with that of the corresponding second order process, we can expect that the cosmic ray shower belongs to higher the order process in Born's theory. Conversely, if the prob. were found to be small, we can ascertain that the convergency of the Born's approximation is good in this case.

Typical third order processes are as follows.

(a) ~~Double Compton scattering~~, in which A photon is scattered by an electron, ~~and splitting at the same time~~ & one more photon being created at the same time.

(b) One of the two photons is disappears, with ~~the production of the and~~ the other being scattered at the same with the production of the pair.

(c) A photon splitts spontaneously into two photons moving in the same direction.

(d) A high ~~electron~~ speed electron loses its energy by emitting two photons at once.

(e) Pair production by nuclear scattering of a photon ~~by a~~

(f) Coherent scattering of a photon by the nucleus.

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The simplest of these is (c), the probability of occurrence of which is found to be 0 to this approximation.† The prob. of occurrence of the process (f) is also 0.†† (to the same approx.) The calculation of the remaining case is so complicated that the exact evaluation of the "spur" in the expression of cross section ~~seems~~ ~~pr~~ are ~~very tedious~~ practically impossible. Heitler and Nordheim* estimated the cross sections in the cases (a) and (d) and found them to be smaller than the corresponding cross sections of second order by factors of order α in both cases.

~~In the pre~~ We carried out similar estimations for the cases (b) and (e), the results of which ~~is~~ are the same as in above cases.

Thus, on the one hand, as pointed out by Heitler and Nordheim, it is not likely that the cosmic ray shower can be explained a higher order process, although its possibility is not completely excluded by such a rough calculation.

On the other hand, the convergency of Born's method of approximation seems good for high energy limit, in spite of the appearance of the logarithmic infinity in ~~some case~~ ~~several~~ some cases. In the present paper, a brief account of the estimation will be given. The notations of Heitler ~~§ 2. Pair Production~~ similar to those ~~by Two Photons~~ and Nordheim, ~~are~~ (will be) used as far as possible.

§ 2. Pair Production by Two Photons

Before entering into the cases (b) and (c), we want to perform the similar estimation for the case of pair pair by two photons, ~~and~~ in order to compare the result with that of the exact calculation[†].

~~The equations of energy and momentum are given by~~

$$\left.\begin{aligned} k_1 + \mu &= E^{(-)} + E^{(+)} \\ (k_1 - \mu)\vec{n}_1 &= \vec{p}^{(-)} + \vec{p}^{(+)} \end{aligned}\right\} \qquad (1)$$

where

We consider that special case, in which two photons moving in ~~the~~ opposite directions with energies ~~$h\nu_1$~~ k_1 and ~~$h\nu_2$~~ μ respectively annihilate and produce an electron of energy $E^{(-)}$ and momentum $\vec{p}^{(-)}/c$ and a positron of energy $E^{(+)}$ and ,, $\vec{p}^{(+)}/c$,

†

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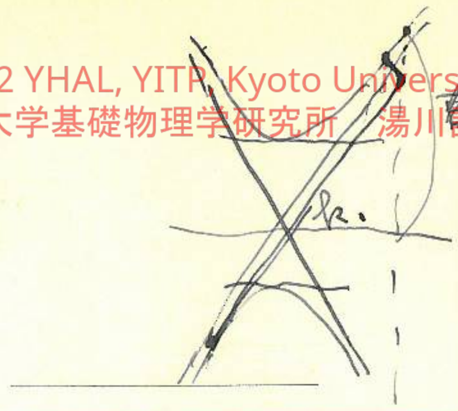

$k_1 + \mu$

$\mu + (p^{(-)} + k)^{\frac{1}{2}}$

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where μ denotes the proper energy mc^2 of the electron.

The equations of energy and momentum are

$$\left.\begin{aligned} k_1 + \mu &= E^{(-)} + E^{(+)}, \\ \text{and} \quad (k_1 - \mu)\vec{n}_1 &= \vec{p}^{(-)} + \vec{p}^{(+)} \end{aligned}\right\} \quad (1)$$

respectively, where $\vec{n}_1$ denote the unit vector in the direction of motion of the first photon.

The differential cross section that the electron is projected to the direction in the solid angle $d\Omega^{(-)}$ is given by

$$d\Phi = \frac{4\pi^2}{hc} \cdot \frac{p^{(-)}E^{(-)}d\Omega^{(-)}}{(hc)^4} \sum_{I,II} \left| \frac{H_{EI}H_{IA}}{E_I - E_A} + \frac{H_{EII}H_{IIA}}{E_{II} - E_A} \right|^2 \quad (2)$$

where the suffixes A, E ~~E, A, I and II~~ denote the ~~final state, ini~~ initial or the final states ~~of the electron~~ ~~and~~ while I or II denotes the intermediate states with energy E_I or E_{II}, in which ~~an electron~~ the first or the second photon is ~~absorbed~~ absorbed with the

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pair production. ~~of~~ $H_{\Sigma\Sigma}$ etc are the corresponding matrix element of the perturbation energy.