SOME OBSERVATIONS ON THE ENERGY SPECTRUM OF LOW ENERGY BREMSSTRAHLUNG FROM ELECTRONS OF ENERGY $\lesssim 10^{12}$ eV

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ABSTRACT. Observations have been made on the energy spectrum of photons of energy greater than 30 MeV emitted by bremsstrahlung from high energy electrons of 10^{11} eV to 10^{12} eV. This observation is of importance from the point of view of checking the influence of the density of the medium. No significant departure from the conventional theory has been observed.

INTRODUCTION

In the past few years, a new aspect of the electrodynamic theory of radiation has evolved from the theoretical prediction of the Russian physicists Landau and Pomeranchuk (1953) and Ter-Mikaelyan (1954), according to whom the probability of bremsstrahlung of low energy photons depends upon the density of the medium In the conventional theory due to Bethe and Heitler (Heitler, 1954) there is no such dependence. According to the new effect, abbreviated as L-P-T, the cross section for the emission of low energy photons is predicted to decrease in media of higher density, as higher initial energies for the primary electron are approached. This influence results from the multiple scattering of the electron and due to the polarisation of the medium On the basis of quantum mechanical considerations, Migdal (1957) has worked out the details of the effect. Curves suitable for comparison with experiment have been given by Varfolomeev *et al* (1958, 1959)*

Nuclear emulsions have a density of ~ 4 g.cm^{-3} and electromagnetic cascades initiated by isolated electrons or photons and by the photons from the π°-mesons created in very high energy interactions are readily available. For primary electron energies greater than or $\sim 10^{11}$ eV and secondary electron pairs due to photons of a few MeV, one expects to check the validity of the theoretical predictions. This article is meant to describe the results of our work and discuss these in the light of the other results available on the subject.

* Thanks are due to Professor Varfolomeev for the communication of the preprint and the reprint.

STATEMENT OF THE PROBLEM

It is important to consider the problem in the light of the experimental observations that can be made. One normally observes a soft shower and obtains its energy from parameters that involve the growth of the shower which is derived from the longitudinal development as given by the cascade theory or from the lateral spread (Pinkau, 1956). There are also alternative methods such as the suppression of ionisation near pair origin (Iwadare 1958) or the true opening angle of the pair (Lohrmann 1955; Aditya 1959 a). The second problem is to detect the secondary pairs and determine the energy of each one of them. When both these quantities are known, the theory can in principle be put to test.

It is well known that the intrinsic fluctuations (Aditya 1959 b) involved in the nature of the processes do not always permit a precise estimation of the primary energy. Results derived from one or a smaller number of cascades are thus subject to uncertainties This limitation can be overcome to a great extent by collecting together a large number of cascades of about the same energy. Another factor that plays a decisive role, is the probability for the detection of low energy electron pairs. In nuclear emulsions the critical energy is ~ 20 MeV so that one is not likely to detect pairs of energy smaller than this value with as good an efficiency as the high energy pairs. The detection efficiency is strongly dependent upon the experimental conditions of observation.

There is yet another factor that influences our conclusions on the effect, as follows · The lack of low energy pairs is strongly dependent on the primary energy, so that one would like to take account of only the first generation pairs due to the bremsstrahlung from the primary electron and not those created from the secondary electrons This distinction between the pairs of the various generations is not straightforward, but has been attempted by some workers (Benisz *et al.*, 1959; Fenyves *et al.*, 1959). In such a procedure there is a possibility of introducing a bias towards the removal of more low energy pairs than the high energy one's. In the light of the considerations given above, the results of the present investigation are given.

EXPERIMENTAL DETAILS

Out of a large number of soft showers picked out from two stacks of stripped emulsions exposed in the stratosphere (Aditya 1959 c), 17 cascades have been selected, the criteria for selection being good conditions of experimental observation There is apparently no bias likely to affect the conclusions on the subject. 3 cascades are associated with a nuclear disintegration (Aditya 1959 d), 5 are initiated presumably by a single electron entering the stack and 9 originate from a single pair. In each case the development has been normalised to a primary electron and the cascades grouped into two bunches : high energy (650, 625, 550, 500, 500, 475, 350, 325)and low energy (250, 225, 200, 125, 50, 50, 40, 40, 40) groups.

The figures in the brackets give for each cascade the energy per electron in GeV. In the case of cascades initiated by a pair, the energy has been assumed to have been equipartitioned between the two electrons. These energies have in most of the cases been determined by the application of different procedures and the most probable value estimated. The individual errors in the energy estimation are expected to have been smoothed out as the cascades of about the same energy have been grouped together.

In order to keep the detection efficiency presumably constant over the entire energy region, we have not attempted to consider the electron pairs of energy loss than 30 MeV. The resulting energy spectrum up to a distance of 1.5 cascade unit has been plotted in the Figs. 1a and 1b, for the two energy intervals. The expected curves for the Bethe-Heitler and Migdal calculations have been included for comparison. We have made no attempt to separate the pairs of various generations on account of the reasons already mentioned. In order to decrease the influence of the pairs of further generations, the measurements have been limited to only the first 1.5 cascade unit from the origin.

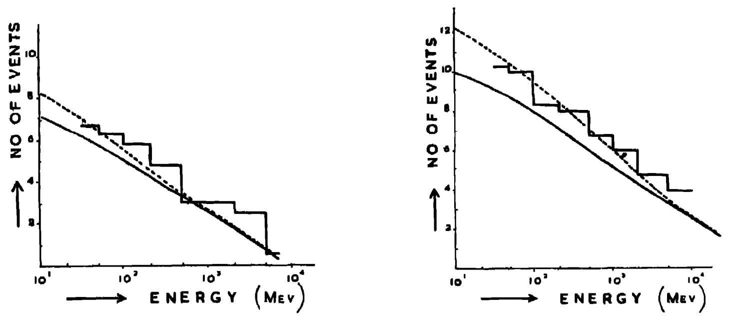

Fig. 1. Energy spectrum for electron pairs observed over the first 1.5 cascade length. The lower limit for acceptable pair energy has been set at 30 MeV (see text)
(a) 9 cascades of median energy 50 GeV per electron. (b) 8 cascades of median energy 500 GeV per electron.

From the figure, it may be seen that subject to the experimental fluctuation a conclusive statement might not be made in favour or against one or the other theory. Since our energies are not extremely high, allowance has to be made for the possibility of the suppression being genuine at higher energies, there being no measurable departure up to $\sim$ 500 GeV energy for primary electrons.

DISCUSSION

It appears useful to compare our results with those of other workers in the field. Varfolomeev *et al.*, (1958, 1959), have studied the spectra for primary energies from 10^{11} eV to 10^{13} eV, and secondary pair energies up to 1.5 MeV. They have found a significant departure from the Bethe-Heitler theory and agreement with L-P-T. It is worth considering that their lower limit of $\sim$ 1 MeV is too low to guarantee uniform detection efficiency over the entire range. In view of this it may not be fair to consider their measurements as having established the existence of the effect.

The second investigation is that of the Polish group (Benisz *et al.*, 1959) who have studied 4 photon-initiated cascades out of which three are associated with a high energy disintegration and the fourth one is that of Miesowicz *et al.*, (1957). The mean energy per electron is $\sim$ 500 GeV, and they have attempted at the separation of the pairs of the first generation from the rest. The lack of low energy pairs might well be accounted for the introduced bias. Their energy region is the same as ours and since our statistics is relatively larger with no effect observed, it may be concluded that the effect if present at these energies is not at least of the order suggested by L-P-T.

There is yet another work by the Czech-Hungary group (Fenyves *et al.*, 1959) in which they have studied the energy spectrum up to 1.5 cascade unit for a cascade initiated by a photon of $\sim$2000 GeV Inspite of the fact that this energy is fairly high (in fact higher than our energies and of Benisz *et al.*) no departure has been noted. The authors have attempted at the separation of the various generation pairs and still observed no divergence from the conventional theory.

In view of the present investigation and of the investigation of other workers mentioned above, it may be concluded that the decrease of bremsstrahlung cross section for low energy photons is not appreciable. This work however does not prove whether the departure would exist at higher energies.

After this work had been finished, the results of the Bristol group (Fowler *et al.*, 1959) have come to our notice* The method is based upon measuring the average distance of materialisation of the first pair for two groups of cascades of different energies. From the distribution of these distances and the mean value for two groups of primary energy 10^{11} eV and 10^{12} eV, they found better agreement with L-P-T than with B-H. Their energy of 10^{12} eV per electron is much higher than most of the other investigations and in view of the large statistics give evidence on the existence of the effect at $\gtrsim 10^{12}$ eV. The actual magnitude of the suppression, whether it is as much as predicted, will have to be determined from the availability of larger statistics.

*Thanks are due to Professor M. G K. Menon for pointing out this paper at the Ahmedabad Symposium, where these results were reported: Annual Cosmic Ray Symposium of the Department of Atomic Energy, March 1959.

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