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Abstract

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Allowance for Pseudotrident Processes in Estimating the Cross Section for Direct Electron-Positron Pair Production by Electrons

(Presented by Academician L. A. Artsimovich, 13 V 1958)

In determining the cross section for direct production of electron-positron pairs by high-energy electrons ("tridents"), it is essential to know the number of so-called "pseudotridents" formed over a given length of the electron track. The latter are produced when bremsstrahlung γ-quanta from the electron are converted in the immediate vicinity of its track. Therefore the set of tracks of the electron and of the pair produced by the γ-quantum cannot be experimentally distinguished from the case of direct production of an electron-positron pair by an electron.

Corrections for the number of pseudotridents were calculated in papers ([1], [2])*. However, in ([1]) the change in the electron energy due to emission of γ-quanta was not taken into account, which should substantially affect the subsequent scattering of the electron and, moreover, the energy spectrum of the emitted photons. The angular distribution of these photons was assumed to be Gaussian. The conversion length was considered identical for γ-quanta of all energies. The calculation in ([2]) was carried out under the same basic assumptions and, in addition, it was assumed that the γ-quantum is emitted only at the beginning of the electron track. Such approximations lead to a certain error in determining the cross section.

In connection with the above, we undertook a calculation of the number of pseudotridents by the Monte Carlo method. The calculations were performed, as in the works mentioned, for nuclear emulsions. The radiation unit of length in the emulsion was taken to be 2.94 cm.

In simulating events associated with the passage of a high-energy electron through matter, the theoretical expressions obtained by Bethe and Heitler ([4], [5]) were used for electron bremsstrahlung, the angular distribution of the emitted quanta, and the cross section for production of electron-positron pairs by γ-quanta, with allowance for screening of the electric field of the nucleus by atomic electrons. The distribution of angles of multiple scattering was taken to be Gaussian. The simulation was also carried out for the bremsstrahlung spectrum of Ter-Mikaelian ([6]), which takes into account the influence of the medium on electron radiation.**

Fig. 1

Figure 1: Fig. 1

The Monte Carlo calculation reduced to the following: the coordinates of the points at which γ-quanta were emitted by the electron were determined, as were the coordinates of the origins of the pairs produced by them and the corresponding deflections of the electron due to multiple scattering. After each emitted quantum, the change in the electron energy was taken into account, and all subsequent processes were simulated with this change included. Three initial electron energies were considered, E: 10^{10}, 10^{11}, 10^{12} eV. For each of the initial energies there was

* The correction obtained in ([1]) is discussed in detail in ([3]).

** The authors considered it possible to disregard the Landau-Pomeranchuk effect ([7]), which, for nuclear emulsions, begins to play a role at electron energies exceeding $\sim 10^{12}$ eV.

was simulated for 105 electrons. The calculation was carried out over an electron track length equal to one radiation unit of length.

Pairs whose distances from the point of origin to the electron are $\rho \leqslant 0.2\,\mu$ are usually regarded as pseudotriples ([1,2]). Since such a criterion is not always applicable under experimental conditions, we have calculated and given in Table 1 and in Fig. 1 the average number of pseudotriples per radiation unit of length, n, for three different criteria ρ.

Table 1*

E, eV	Total number of pairs per 10^5 rad. units of length	n, $\rho \leqslant 0.2\,\mu$	n, $\rho \leqslant 0.3\,\mu$	n, $\rho \leqslant 0.4\,\mu$	Bremsstrahlung spectrum
10^{10}	193	0.18 ± 0.05	0.24 ± 0.05	0.27 ± 0.05	BG
10^{10}	191	0.18 ± 0.05	0.24 ± 0.05	0.27 ± 0.05	TM
10^{11}	346	1.03 ± 0.08	1.4 ± 0.1	1.7 ± 0.1	BG
10^{11}	303	0.86 ± 0.08	1.12 ± 0.09	1.4 ± 0.1	TM
10^{12}	402	3.3 ± 0.2	3.6 ± 0.2	3.6 ± 0.2	BG
10^{12}	282	2.2 ± 0.1	2.4 ± 0.1	2.5 ± 0.1	TM

* The errors of n are defined as standard fluctuations. BG is the Bethe-Heitler bremsstrahlung spectrum. TM is the Ter-Mikaelian bremsstrahlung spectrum.

Fig. 1. Number of pseudotriples per radiation unit of length as a function

Fig. 2

Figure 2: Fig. 2

of the initial energy of the electron. BG is the Bethe-Heitler bremsstrahlung spectrum; TM is the Ter-Mikaelian bremsstrahlung spectrum. $\rho \leqslant 0.2\,\mu$.

Fig. 2. Ratio of the number of pseudotriples to the total number of pairs K as a function of the electron track length T. $\rho \leqslant 0.2\,\mu$. The smooth curves for $E = 10^{10}$ eV and $E = 10^{11}$ eV are taken from Ref. ([3]).

As can be seen from the data presented, the number of pseudotriples depends rather weakly on the criteria we give. A rough estimate of the number of pseudotriples in the case of intermediate energies may be made from the curve in Fig. 1.

In Fig. 2 the correction for the number of pseudotriples is presented in the form adopted in (1), i.e., as the ratio of the number of pseudotriples to the total number of electron–positron pairs formed in the conversion of γ-quanta,

emitted by the electron. From a comparison of the corrections it follows that the number of pseudotriples obtained in the present work is smaller than the corresponding number of pseudotriples according to ([1]); in other words, the cross section for the formation of triples, calculated with the aid of the number of pseudotriples obtained by us, is larger than the cross section determined according to ([1]).

Table 2

E, Bev	Number of visible triples	Number of triples: correction according to ([1])	Number of triples: according to the present work	Number of triples according to Bhabha's theory ([9])	Lit. source
10–100	1.1 ± 0.4	0.9 ± 0.4	0.6 ± 0.4	0.11–0.19	([1])
2.5–60	0.6 ± 0.2	0.1 ± 0.2	0.2 ± 0.2	0.08–0.17	([8])

It is of interest to estimate, with the aid of the number of pseudotriples found by us, the number of cases of direct pair formation by electrons according to the data of various authors. The results of such an estimate for one radiation unit of length are given in Table 2, where the number of visible triples is the sum of the numbers of triples and pseudotriples for the criterion $\rho \leq 0.2\,\mu$. The indicated errors are Poisson errors. The contradictory data on the number of triples obtained when two different corrections are applied attract attention.

Application of the results of the present work gives close values for the number of triples in both intervals of electron energies, whereas between the numbers of triples obtained with the aid of the correction according to ([1]) there is a considerable discrepancy, which is difficult to explain by the difference in electron energies. We note that the correction according to ([1]) depends substantially on the total number of electron–positron pairs on a given length of electron track. In ([1]), the total number of pairs was determined experimentally, whereas in ([8]) it was calculated theoretically.

The reason for the above-mentioned contradiction possibly lies in the fact that the total number of pairs found in ([1]) (0.8 ± 0.3 per rad. unit of length) differs substantially from the corresponding theoretical value (2.2 per rad. unit of length) (see ([8])).

Apparently, in ([1]) there was either a significant fluctuation or a systematic error associated with missing some number of pairs located sufficiently far from the electron track, as a result of which the number of triples proved to be overestimated.

The number of triples calculated from the data of ([1],[8]) with the correction according to ([1]), using the theoretical value for the total number of pairs, does not exceed the number of triples according to Bhabha' s theory ([9]). Meanwhile, the number of cases of direct pair formation by electrons calculated from these data with the aid of the number of pseudotriples obtained in the present work exceeds the corresponding number of triples calculated with the correction according to ([1]), but the considerable experimental errors do not allow definite conclusions to be drawn about the magnitude of the cross section in comparison with the theoretical one.

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Note: Figure translations are in progress. See original paper for figures.